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DESIGN AND TESTING OF A PROTOTYPE AUTOMATIC SEWER SAMPLING SYSTEM

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DESIGN AND TESTING OF A PROTOTYPE AUTOMATIC SEWER SAMPLING SYSTEM

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The prototype sampler is described from an installation and operation viewpoint, and the results of preliminary field testing are discussed. The device was also tested under controlled laboratory conditions and found to be capable of gathering reasonably representative samples (i.e., within 10%) over a fairly wide range of flow characteristics, even for particles somewhat outside the regime of Stokes' Law. Four different commercially available samplers were tested under the same flow conditions in a side by side fashion. Their behavior was rather erratic, and they were not able to gather representative samples consistently. None of them was capable of good performance when appreciable bed load was present. Results from these commercial units ranged from an overall understatement of pollutant loading by 25% or more, to overstatements of 200% and more.

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DESIGN AND TESTING OF A PROTOTYPE AUTOMATIC SEWER SAMPLING SYSTEM

by

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The deleterious effects of storm and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. Efforts to alleviate the problem depend upon accurate characterization of these flows in both a quantity and quality sense. This report describes the consideration that led to the design and fabrication of a prototype automatic sewer sampling system specifically intended for application in a storm or combined sewer. It also presents the results of preliminary field testing and controlled laboratory testing, and will be of interest to those who have a requirement for the quality characterization of wastewater flows.

Louis W. Lefke
Acting Director
Municipal Environmental
Research Laboratory

ABSTRACT

A brief review of the characteristics of storm and combined sewer flows is given, followed by a discussion of the requirements for equipment to sample them, noting features that are desirable in such equipment and problem areas. When considered from a systems viewpoint, there are five functional subsystems. Design considerations for each of these are discussed, followed by a description of the design implementation used for each subsystem in the fabrication and assembly of a prototype automatic sewer sampling system intended for storm and combined sewer application and other adverse sewer flow conditions.

The prototype sampler is described from an installation and operation viewpoint, and the results of preliminary field testing are discussed. The device was also tested under controlled laboratory conditions and found to be capable of gathering reasonably representative samples (i.e., within 10%) over a fairly wide range of flow characteristics, even for particles somewhat outside the regime of Stokes' law. Four different commercially available samplers were tested under the same flow conditions in a side by side fashion. Their behavior was rather erratic, and they were not able to gather representative samples consistently. None of them was capable of good performance when appreciable bed load was present. Results from these commercial units ranged from an overall understatement of pollutant loading by 25% or more, to overstatements of 200% and more.

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PREFACE

Readers of this report who are interested in more detail about commercially available automatic liquid samplers, custom designed units, and project and field experience with such devices in storm and combined sewers are referred to a collateral effort reported in an Environmental Protection Technology Series Report entitled "An Assessment of Automatic Sewer Flow Samplers - 1975." It presents a brief review of the characteristics of storm and combined sewer flows followed by a general discussion of the purposes for and requirements of a sampling program. A compendium of 82 model classes covering over 200 models of commercially available and custom designed automatic samplers is given with descriptions and characterizations of each unit presented along with an evaluation of its suitability for a storm and/or combined sewer application. A review of field experience with automatic sampling equipment is also given covering problems encountered and lessons learned.

SECTION I

CONCLUSIONS

1. Storm and combined sewer flows are the most difficult of all wastewater streams to accurately characterize in a water quality sense due to the extremely wide range of pollutants that can be found in them, the possible spatial variations of these pollutants within a given cross-section of the flow, the widely varying flow rates commonly encountered that can even include reverse flow in certain situations, the frequent presence of significant bed load which may be highly polluted, the presence of every imaginable kind of debris which poses a physical threat to any obstacle in the flow, and so on.

2. In view of the large number of highly varying parameters associated with the storm and combined sewer application, a systems approach to the design of an automatic sampler intended for such use is virtually mandatory; the five essential elements of such a system are the sampler intake subsystem, the sample gathering subsystem, the sample transport subsystem, the sample storage subsystem, and the controls and power subsystem.

3. Based upon a functional analysis of each subsystem of an automatic sewer sampler, in the light of the present state-of-the-art, a number of improvements are both warranted and achievable, including areas such as intake design, sample intake and transport velocity, sample train line sizes, and sample capacity.

4. A prototype automatic sewer sampling system intended expressly for the storm and combined sewer application was designed and fabricated using a modular approach, which allows the basic design implementation to be tailored to suit a wide variety of sampling program and site requirements. The design features include all solid-state electronics, a clock to allow time-of-day correlation, high sample intake and transport velocities, minimum line size of 0.95 cm (3/8 in.) inside diameter, large peristaltic pumps and fluidic

diverters to avoid having any moving parts in the sample train, the return of the first flow to waste, a fresh water purge and backflush before and after each sample is taken, multilevel sample intakes with non-intrusive mounting, and large sample capacity.

5. The prototype sampler was given some preliminary field testing in an actual sewer following extensive bench testing and check-out. It performed very well overall with very little de-bugging required as a result of actual field operation. It was discovered that the pumps are powerful enough to pick up relatively large stones that could damage the tubing in the pump, and so intake screens with a maximum aperture size of 0.48 cm (3/16 in.) are used. It was also learned that if an intake is not completely submerged, the resulting air bubbles in the flow may cause erratic fluidic diverter action. Finally, attention must be given to the orientation and routing of the sample return (drain) line so that it does not kink as the sample distribution arm rotates.

6. The prototype sampler was tested in synthetic sewage flows under laboratory conditions that were controlled as to flow velocity, depth, and suspended solids density, size, and concentration in order to evaluate its ability to gather samples that are representative in terms of suspended solids. Although good results were achieved when most of the particles were in suspension in the flow (even for those falling somewhat outside the range of validity of Stokes' Law), results tended to be erratic when any appreciable quantity of material was transported as bed load.

7. Four different types of commercially available automatic samplers from four different manufacturers were tested side by side with the prototype sampler under selected, controlled laboratory conditions. Performances, as measured by laboratory analysis of their samples, were quite erratic. Although the testing was far from exhaustive, enough data were gathered to demonstrate that there can be marked differences in results obtained with different types of sampling equipment, even under identical, controlled flow conditions.

8. It was not the purpose of this brief series of comparative tests to evaluate the different design approaches used by commercial manufacturers of automatic sampling equipment. The results of the tests do point out the critical urgency for such work to be performed, however. As suggested by other work and demonstrated by the present effort, some water quality data now in existence may be considered suspect, at least insofar as suspended solids are concerned. Thus, there is a need for determining the capabilities of various types of sample collection systems to gather representative samples of wastewater flows over a wide range of characteristics. This is especially critical for equipment to be used in storm and combined sewer flows which often contain large amounts of heavier suspended solids.

9. The prototype sampler was not designed to sample bed load or floatables in a truly representative sense, and no claims should be inferred as to its ability to do so. Such sampling is necessary, especially in a storm or combined sewer, if one is to be able to account for all pollutant loadings in a time-mass-discharge sense, but no equipment exists today that is well suited for these purposes.

10. The new technologies implemented in the design of the prototype sampler have demonstrated efficacy, and should be considered in the design of commercially available equipment. One possible exception is the fluidic diverter. A simple pinch-tube valve arrangement could offer similar design advantages at less cost. The trade off lies between the likelihood of debris in the flow interfering with the operation of the pinch valve (i.e., preventing it from closing completely) and the likelihood of air bubbles in the flow causing sluggish fluidic diverter action.

SECTION II

RECOMMENDATIONS

1. The ability of the prototype automatic sewer sampling system to gather representative samples over a wide variety of flow conditions and to operate in an actual sewer setting has been demonstrated. It is recommended that it be installed at some on-going USEPA demonstration project where comparative data are desired.

2. When combined with earlier field experience, the erratic results obtained with different types of commercially available automatic samplers under controlled laboratory conditions points out the urgent need for determining the capabilities of various types of sample collection systems to gather representative samples of wastewater flows over a wide range of characteristics. This must be done under controlled conditions if results are to be quantified in any way other than as relativistic comparisons. It is recommended that a number of sample collection systems of the types that represent the majority of present day equipment be assembled and tested under controlled laboratory conditions representing a wide range of wastewater flow characteristics.

3. Representative sampling of bed load and floatables (including oil and grease) continues to be an extremely difficult problem. It is recommended that a program to develop equipment that is suitable for these purposes be initiated in the near future.

SECTION III
INTRODUCTION

GENERAL

The phenomenal growth of urban areas in recent times and the rapid expansion of industrial operations to meet society's ever increasing demands for more goods, energy, etc., have heightened the pollutional potential of man's existence and have contributed to his increasing awareness of and concern for his environment. One of the impacts of the population explosion is that sanitary engineering practices that appeared tolerable even as recently as a few decades ago are no longer acceptable today in many locales. The pollutional effects of stormwater and combined sewer overflows on receiving water quality are becoming less and less tolerable, and a research program to mitigate or ameliorate the situation has been underway at the USEPA (and its predecessor agencies) for the last several years.

Knowledge of the character of the urban environment leads one to the expectation that stormwater draining from it will be of poor quality, and more and more data are being gathered that verify this expectation. Although a discussion of urban runoff quality is beyond the scope of this presentation, it should be noted here that the nature of urban runoff, its temporal and spatial fluctuations, and the characteristics of urban catchment systems all contribute to make gathering accurate flow characterization data, both quantity and quality, a very difficult task. Uncontrollable parameters include meteorological and climatological factors, topography, hydraulic characteristics of the surface and subsurface conduits, the nature of the antecedent period, and the land use activities and housekeeping practices employed.

An automatic liquid sampler is a highly desirable tool to employ in determining the water quality characteristics of storm and combined sewer flows. A review (1) of the majority of commercially available automatic liquid samplers revealed that none had been specifically designed for this severe application and, in fact, many manufacturers do not recommend their equipment for such use. As a result, a new automatic sewer sampling system was designed incorporating several new technological advances.

If one considers all of the vagaries of the storm and combined sewer sampling problem presented in (1), it is intuitively obvious that a single piece of equipment cannot

exist that is ideal for all sampling programs in all storm and combined sewer flows of interest. One can, however, set down some general requirements for sampling equipment that is to be used in a storm or combined sewer application.

EQUIPMENT REQUIREMENTS

The success of an automatic sampler in gathering a representative sample starts with the design of the sampler intake. This obviously will be dependent upon conditions at the particular site where the sample is to be extracted. If one is fortunate enough to have a situation where the sewer flow is homogeneous with respect to the parameters being sampled, then a simple single point of extraction for the sample will be adequate. In the more typical case, however, there may be a spatial variation in the concentration of a particular constituent that is to be examined as part of a sampling program, and then the sampling intake must be designed so that the sample which is gathered will be nearly representative of the actual flow. Several different designs have been utilized by researchers in an attempt to meet this objective, but none can be considered as ideal or universally applicable.

The automatic sampler must be capable of lifting the sample to a sufficient height to allow its utilization over a rather wide range of operating heads. It would appear that a minimum sample lift of 5 meters (15 ft) or so is almost mandatory in order to give a fairly wide range of applicability. It is also important that the sample size not be a function of the sample lift; that is, the sample size should not become significantly less as the sample lift increases.

The sample line size must be large enough to give assurances that there will be no plugging or clogging anywhere within the sampling train. However, the line size must also be small enough so that complete transport of suspended solids is assured. Obviously, the velocities in any vertical section of the sampling train must well exceed the settling velocity of the maximum size particle that is to be sampled. Thus, the sample flow rate and line size are connected and must be approached together from design considerations.

The sample capacity that is designed into the piece of equipment will depend upon the subsequent analyses that the sample is to be subjected to and the volumetric requirements for conducting these analyses. However, in general, it is desirable to have a fairly large quantity of material on hand, it being safer to err on the side of collecting too much rather than too little. As a minimum, it would seem that at least 500 mℓ and preferably 1000 mℓ of fluid would

be desirable for any discrete sample. For composite samples at least 4 to 8 liters should be collected.

The controls on the automatic sampler should allow some degree of freedom in the operation and utilization of the particular piece of equipment. A built-in timer is desirable to allow preprogrammed operation of the equipment. Such operation would be particularly useful, for example, in characterizing the buildup of pollutants in the early stages of storm runoff. However, the equipment should also be capable of taking signals from some flow measuring device so that flow proportional operation can be realized. It is also desirable that the equipment be able to start up automatically upon signal from some external device that might indicate the onset of storm flow phenomena such as an external rain gauge, flow height gauge, etc. Flexibility in operation is very desirable.

A power source will be required for any automatic sampler. It may take the form of a battery pack or clock type spring motor that is integral to the sampler itself. It may be pressurized gas, air pressurized from an external source, or electrical power, depending upon the availability at the site.

In addition to being able to gather a representative sample from the flow, the sampling equipment must also be capable of transporting the sample without pre-contamination or cross-contamination from earlier samples or aliquots and of storing the gathered sample in some suitable way. As was noted in (1), chemical preservation is required for certain parameters that may be subject to later analyses, but refrigeration of the sample is also required and is stated as the best single means of preservation.

DESIRABLE FEATURES

In addition to the foregoing requirements of automatic sampling equipment, there are also certain desirable features which will enhance the utility and value of the equipment. For example, the design should be such that maintenance and troubleshooting are relatively simple tasks. Spare parts should be readily available and reasonably priced. The equipment design should be such that the unit has maximum inherent reliability. As a general rule, complexity in design should be avoided even at the sacrifice of a certain degree of flexibility of operation. A reliable unit that gathers a reasonably representative sample most of the time is much more desirable than an extremely sophisticated complex unit that gathers a very representative sample 10 percent of the time, the other 90 percent of the time being

spent undergoing some form of repair due to a malfunction associated with its complexity.

It is also desirable that the cost of the equipment be as low as practical both in terms of acquisition as well as operational and maintenance costs. For example, a piece of equipment that requires 100 man-hours to clean after each 24 hours of operation is very undesirable. It is also desirable that the unit be capable of unattended operation and remaining in a standby condition for extended periods of time.

The sampler should be of sturdy construction with a minimum of parts exposed to the sewage or to the highly humid, corrosive atmosphere associated directly with the sewer. It should not be subject to corrosion or the possibility of sample contamination due to its materials of construction. The sample containers should be capable of being easily removed and cleaned; preferably they should be disposable.

PROBLEM AREAS

The sampler by its design must have a maximum probability of successful operation in the very hostile storm and combined sewer environment. It should offer every reasonable protection against obstruction or clogging of the sampling ports and, within the sampler itself, of the sampling train. It is in a very vulnerable position if it offers any significant obstruction to the flow because of the large debris which are sometimes found in such waters. The unit must be capable of operation under the full range of flow conditions which are peculiar to storm and combined sewers and this operation should be unimpeded by the movement of solids within the fluid flow. If the unit is to be designed for operation in a manhole, it almost certainly should be capable of total immersion or flooding during adverse storm conditions which very frequently cause surcharging in manhole areas. It is also necessary that the unit be able to withstand and operate under freezing ambient conditions, and that it be able to withstand the high flow velocities and the associated high momentums found in storm and combined sewer flows.

Probably one of the most significant problem areas lies in the attempt to gather a sample that is representative of low as well as high specific gravity suspended solids. The different momentum characteristics call for differing approaches in sampler intake design and in intake velocities. Another problem area arises in a sampling program where it

is desirable to sample floatable solids and materials such as oils and greases as well as very coarse bottom solids and bed load proper.

For samples which are to be analyzed for constituents which require chemical fixing soon after the sample is collected, there are other problems. Although it is true that the required amount of fixing agent could be placed in the sample container prior to placing it in the field, for composite samples in particular, where the eventual total sample is built up of smaller aliquots gathered over an extended period of time, the initial high concentrations of the fixing agent as it becomes mixed with the early aliquots may well be such as to render the entire sample unsuitable for its intended purpose.

Another problem area is the selection of materials in the sampling train, i.e., those that come in contact with the sample in any way. Adsorption of certain pollutants by these materials could affect sample representativeness, but there is no universally acceptable material due to the wide diversity of pollutant activities.

Probably the greatest problem areas lies in the inability to produce a single design that is all things to all people. This means that a number of extensive trade-off studies are required. Care must be taken, however, that the resultant design is not so "optimized" (i.e., compromised) that it is not really well suited for any particular application or use.

SECTION IV

SAMPLER DESIGN CONSIDERATIONS

SAMPLER

In a system breakdown of an automatic sewer sampler by functional attributes, it may be divided into five basic elements or subsystems. These will be identified and discussed in turn from the viewpoint of their design considerations.

SAMPLER INTAKE SUBSYSTEM

The sample intake of many commercially available automatic liquid samplers is often only the end of a plastic suction tube, and the user is left to his own ingenuity and devices if he desires to do anything other than simply dangle the tube in the stream to be sampled. In the following paragraphs we wish to examine the functions of a sampler intake that is intended to be used in a storm or combined sewer application and the design considerations that arise therefrom.

Pollutant Variability

A general discussion of the character of storm and combined sewage is given in (1) where the variability of pollutant concentration is also treated. We wish to consider the latter factor here in somewhat more detail. Let us consider first some empirical data from (2). In the study, a special pressurized circulating loop was assembled containing a 25 cm (10 in.) square test section some 4.6m (15 ft.) long. Careful measurements of the velocity contours were made and near uniformity was observed. Since the variability of a pollutant will be a function of velocity variations (among other factors), it is of interest to note the horizontal and vertical variations of sediment distribution observed experimentally in this test section with its very small velocity variation.

Four readily available commerical sands, differing principally in size, were used in the study. They are referred to by mean particle size (50 percent finer by weight) as 0.45 mm, 0.15 mm, 0.06 mm and 0.01 mm. Observed sediment

distribution for the three coarsest sands are indicated in figure 1. For all practical purposes the 0.01 mm sand was uniformly distributed. It should be noted here that the vertical variation is probably enhanced due to the design of the test loop, which would tend to enhance concentrations of heavier particles to the outside (the bottom of the test section in this case) due to the action of centrifugal forces. Observations made in (3) markedly indicate this effect.

The observation was made in (3) that, in addition to variations in sediment concentration within the cross-section at a given time, the sediment concentration at any point in the cross-section was highly variable with respect to time, especially for the coarser sediments (0.45 mm). This observation was also made in (2) where data are presented on concentration variation with respect to time as a function of sampling interval. The concentration of successive 20-second samples was found to vary over a range of 37 percent of the mean, and the concentration of successive 60-second samples varied over a range of 10.5 percent. Such variations arise from the natural turbulence of the flow as would be encountered in an actual sewer and from the non-uniform nature of recirculated flows in test loops which is peculiar to laboratory simulations.

So far we have focused our attention on relatively heavy (specific gravity approximately 2.65) solids and their distribution in a flow. For the lighter organic solids with specific gravities near unity, the particle distribution will be more nearly uniform in a turbulent flow. It would appear that one can expect a reasonable degree of uniformity in the distribution of particles which fall in the Stokes' Law range of settling velocities, i.e., for values of the external Reynolds' number less than unity. If one describes a particle in terms of its hydraulic size W, defined as the velocity of uniform fall in a fluid at rest, Stokes' Law can be written as

$$W = gd^2 \ (s.g.-1)/18\nu \qquad [1]$$

where d is mean particle diameter, s.g. is the specific gravity of the particle material, ν is the kinematic viscosity of the fluid, and g is the acceleration of gravity. The external Reynolds' number (so called because the linear dimension upon which it is based is a particle dimension rather than a flow dimension) can be expressed as

$$Re = Wd/\nu \qquad [2]$$

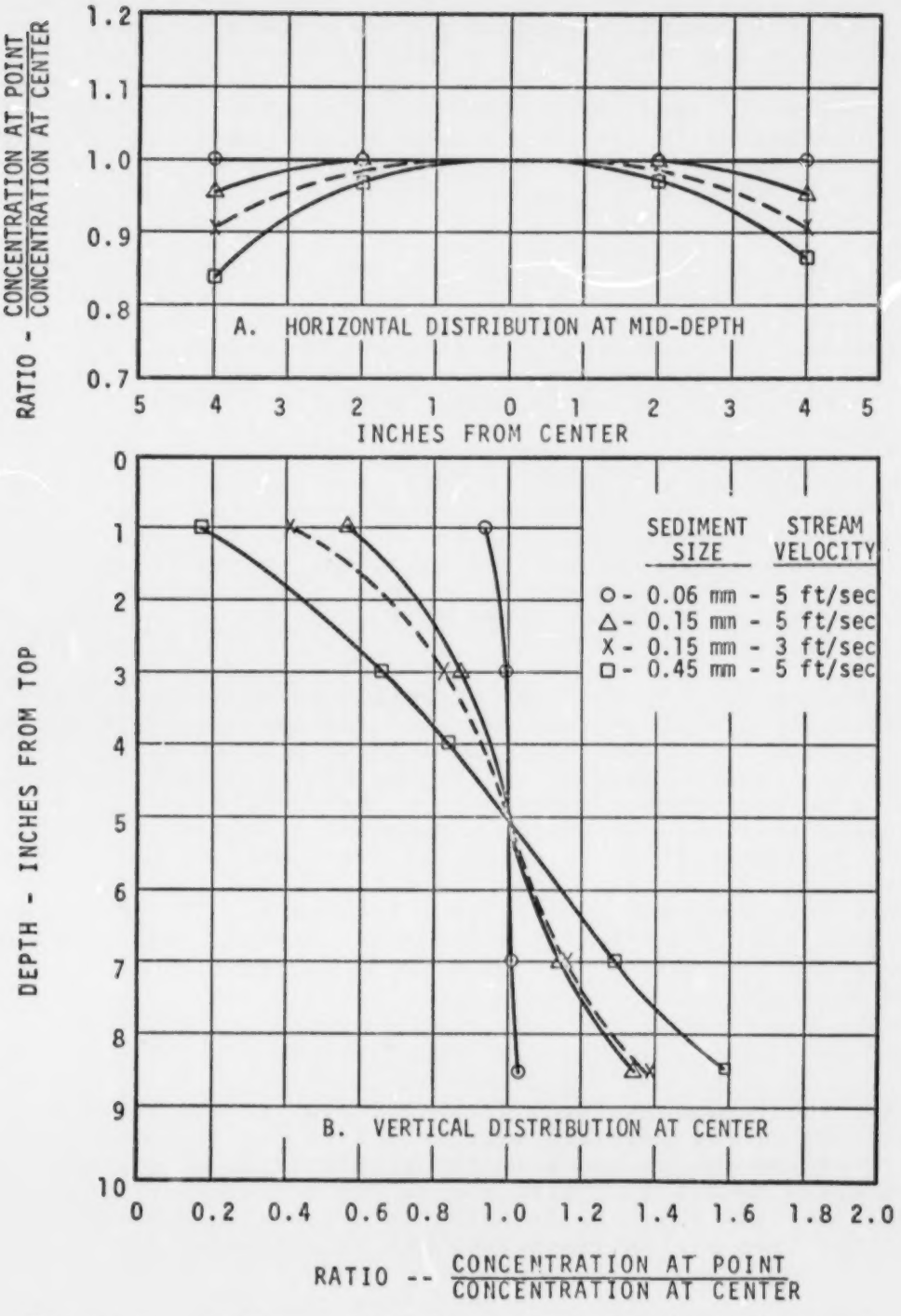

RATIO - CONCENTRATION AT POINT / CONCENTRATION AT CENTER
1.2
1.1
1.0
0.9
0.8
0.7
A. HORIZONTAL DISTRIBUTION AT MID-DEPTH
5 4 3 2 1 0 1 2 3 4 5
INCHES FROM CENTER
DEPTH - INCHES FROM TOP
0 1 2 3 4 5 6 7 8 9 10
SEDIMENT SIZE
STREAM VELOCITY
○ - 0.06 mm - 5 ft/sec
△ - 0.15 mm - 5 ft/sec
X - 0.15 mm - 3 ft/sec
□ - 0.45 mm - 5 ft/sec
B. VERTICAL DISTRIBUTION AT CENTER
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
RATIO -- CONCENTRATION AT POINT / CONCENTRATION AT CENTER

Figure 1. Sediment Distribution at Sampling Station*

* Taken from reference 2.

Combining equations [1] and [2] we can express the range of validity of Stokes' Law as

$$Re = gd^3 (s.g.-1)/18\nu^2 < 1 \qquad [3]$$

If one considers water at 16°C (60°F) as the fluid (ν=1.217 x10^{-5} ft^2/sec), a plot of equation [3] over the range of interest is given in figure 2. Here it can be noted that, within the range of Stokes' Law, the maximum particle diameter for sand with a specific gravity of 2.65 is less than 0.1 mm while for organic particles with a specific gravity of 1.05 it is about 0.3 mm.

Since the kinematic viscosity of water is temperature dependent, the Stokes' Law particle diameter limit will also be a function of temperature. For sand, a decrease in water temperature from the upper eighties to the mid-forties results in a 50 percent increase in the maximum particle diameter.

Sampler Intake Functions

The operational function of a sampler intake is to reliably allow gathering a representative sample from the flow stream in question. Its reliability is measured in terms of freedom from plugging or clogging to the degree that sampler operation is affected, and invulnerability to physical damage due to large objects in the flow. It is also desirable, from the viewpoint of sewer operation, that the sampler intake offer a minimum obstruction to the flow in order to help prevent blockage of the entire sewer pipe by lodged debris, etc.

Let us first consider the ability of the intake to gather a representative sample of dense suspended solids in the sediment range, say up to 0.5 mm with specific gravity of 2.65. The results of a rather thorough examination of relatively small diameter intake probes 0.63 and 0.32 cm (1/4 and 1/8 in.) are given in (2). The argument is developed that, for a nozzle pointing directly into the flow (figure 3a), the most representative sample of a fluid/suspended-solids mixture will be obtained when the sampling velocity is equal to the flow velocity at the sampling point. Using this as the reference criteria, investigations were conducted to determine the effects of a) deviations from the normal sampling rate, b) deviations from the straight-into-flow position of the probe, c) deviations in size and shape of the

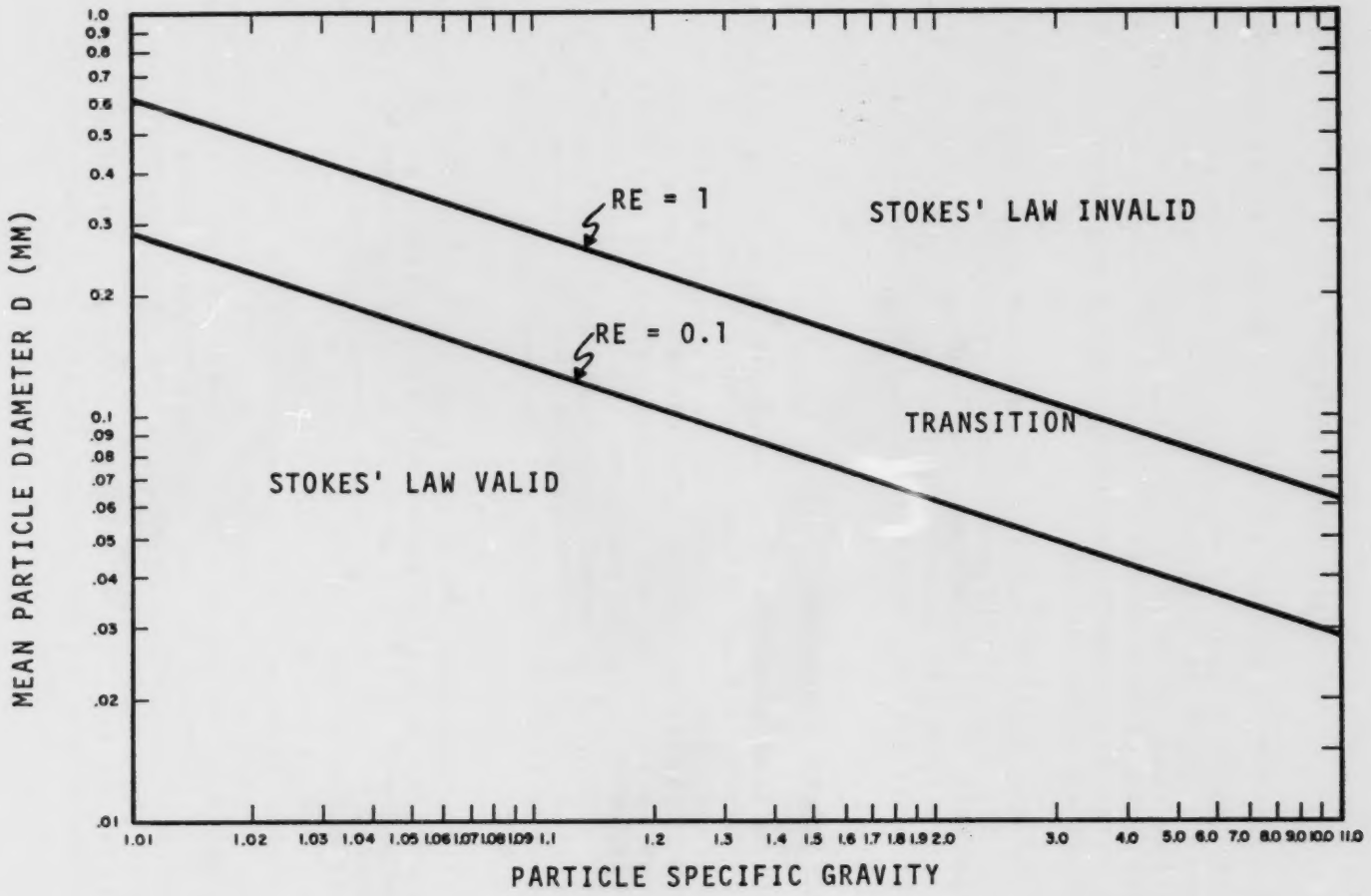
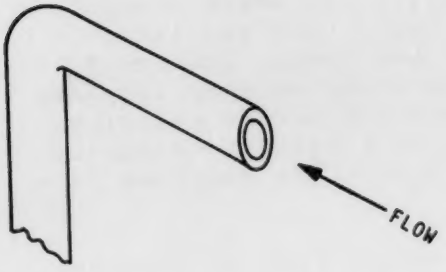
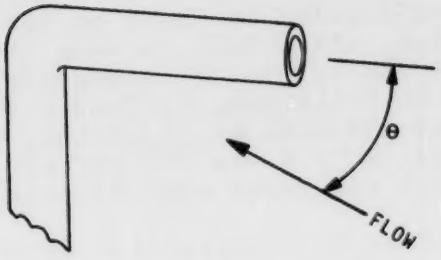


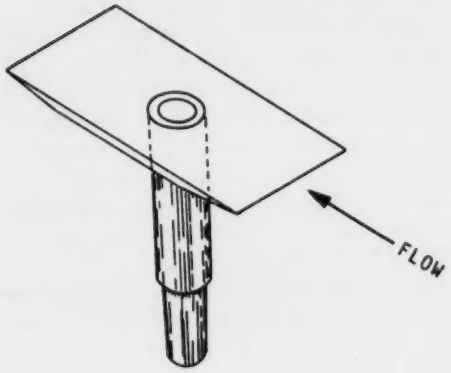
Figure 2. Region of Validity of Stokes' Law



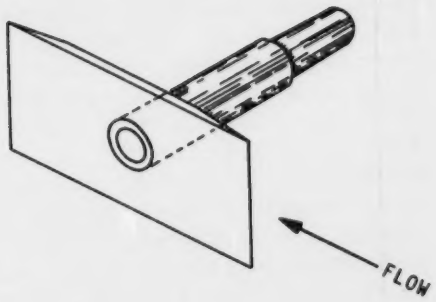
3a. Normal Orientation Directly Into Flow



3b. Orientation at an Angle to Head-on



3c. Vertical Orientation (0°)- Orifice in Flat Plate



3d. Horizontal Orientation (90°) - Orifice in Flat Plate

Figure 3. Orientation Angles

probe, and d) disturbance of sample by nozzle appurtenances. The effect of the sampling velocity on the representativeness of the sample is indicated in figure 4, which presents the results for 0.45 mm and 0.06 mm sand. For the latter size, which falls within the Stokes' Law range, less than ±4 percent error in concentration was observed over sampling velocities ranging from 0.4 to 4 times the stream velocity. For the 0.45 mm particles, the error at a relative sampling rate of 0.4 was +45 percent, and at a relative sampling rate of 4 the error was -25 percent.

For probe orientations up to 20° to either side of head-on, (figure 3b), no appreciable errors in concentration were observed. Similarly, introduction of 0.381 and 0.952 cm (0.150 and 0.375 in.) probes showed comparatively little effect on the representativeness of the sample. The probe inlet geometry, i.e., beveled inside, beveled outside, or rounded edge, also showed little effect on the representativeness of the sample, when compared to the standard probe. Finally, in instances where a sampler body or other appurtenance exists, the probe should be extended a short distance upstream if a representative sample is to be collected. In summary, it was found that for any sampler intake facing into the tream, the sampling rate is the primary factor to be controlled.

Tests were also run with the sampling intake probes in the vertical position (figure 3c) to determine the effect such as orientation had upon the representativeness of the sample. With such intakes, the sample entering them must undergo a 90° change of direction, and consequently there is a tendency for segregation and loss of sediment to take place. Tests were run with the standard probe, a 0.63 cm (1/4 in.) diameter orifice in the center of a 2.5 x 5.1 cm (1 x 2 in.) flat plate oriented so that its longest dimension was in the direction of flow, and with an orifice in a crowned (mushroom shaped) flat plate 3.2 x 5.1 cm (1.25 x 2 in.). The results all showed negative errors in concentration, increasing with particle size and increasing with intake velocities less than the stream rate but nearly constant for intake velocities higher than the stream rate.

Since the smallest errors were found for the orifices in the flat and mushroom shaped plates (whose performances were nearly identical for intake velocities greater than one-half the stream velocity), it was decided to investigate the effect of lateral orientation, i.e., to rotate the plate 90° so that it might represent an orifice in the side of a conduit rather than in the bottom (figure 3d). The results for 0.15 mm sand are presented in figure 5. It can be noted that while side orientation caused greater errors (as was

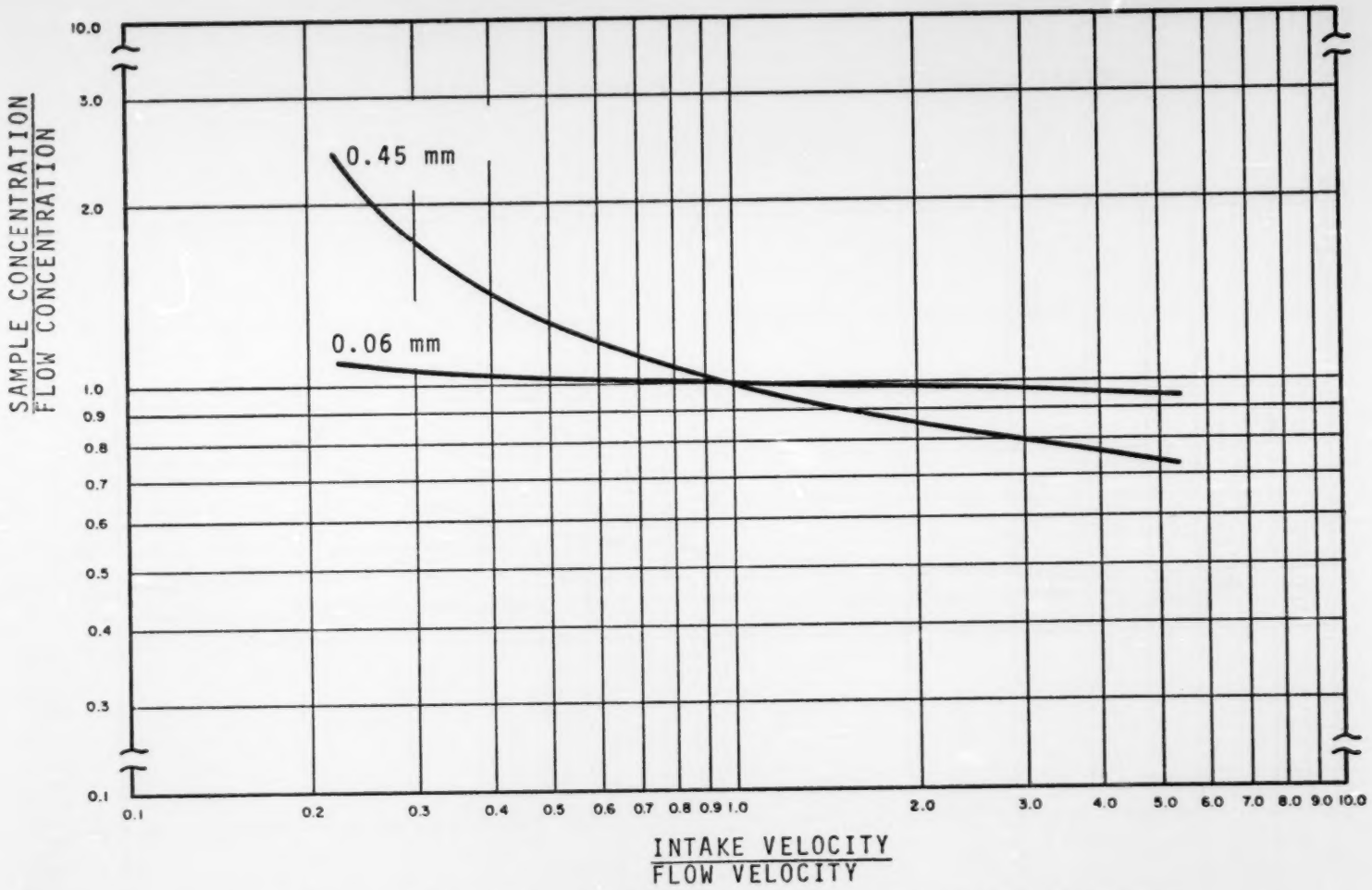


Figure 4. Effect of Sampling Velocity on Representativeness of Suspended Solids*

* Data from reference 2.

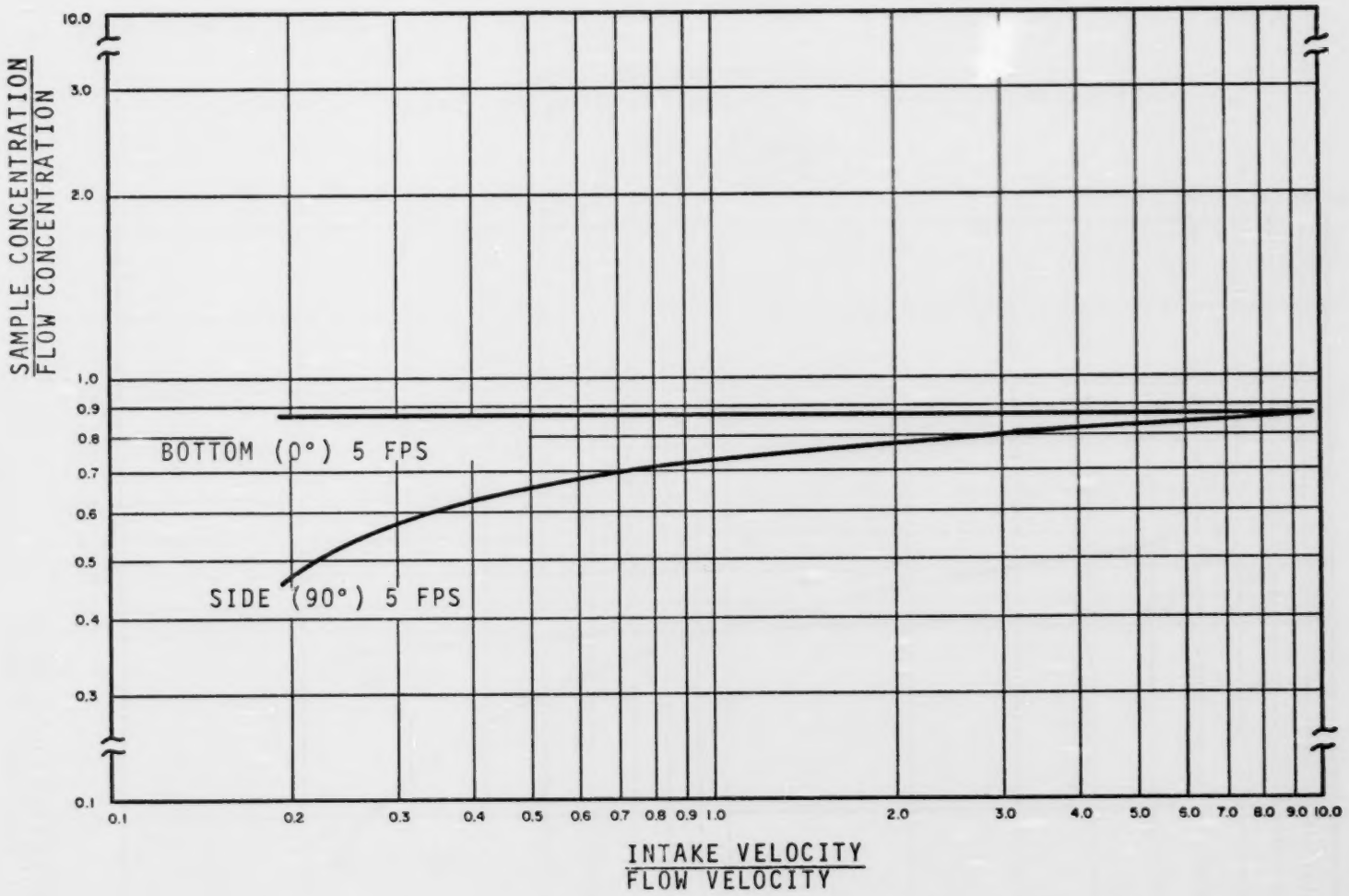


Figure 5. Effect of Lateral Orientation of Sample Intake*

* Data taken from reference 2.

to be expected), these errors approached the nearly constant error of the 0° orientation as the relative sampling rate was increased above unity.

The work reported in (3) was a laboratory investigation of pumping sampler intakes. Nine basic intake configurations, all representing an orifice of some type in the side wall of the flume, were examined. Sand sizes of 0.10 mm and 0.45 mm were used in the study. Reference samples were taken with a probe located near the wall and pointing into the direction of the flow. The reference sample intake velocity was equal to the stream velocity. The primary measurement was sampling efficiency, the ratio of the sediment concentration in the test sample to that of the reference sample computed for a point 1.3 cm (1/2 in.) from the wall. The reference sample was taken just before and just after the test sample was gathered. Although the data exhibited considerable scatter, several conclusions were drawn. With regard to the intake velocity, greater than 0.9 m/s (3 fps) is generally desirable and, for sands coarser than 0.2 mm, an intake velocity equal to or greater than the stream velocity is desirable. With regard to intake configuration, for intake velocities greater than about 0.9 m/s (3 fps) the sampling efficiencies showed little effect of size of intake (range was 1.3 to 3.8 cm diameter), of rounding the intake edges, or of shape and orientation of the axis of an oval intake. Sampling efficiency was found to decrease with increasing particle size above 0.10 mm for all intakes tested. Similar observations were made in field tests with river water samples at St. Paul and Dunning, Nebraska, reported in (4).

To summarize the foregoing as it relates to the sampler intake function of gathering a representative sample we note the following:

1) It becomes difficult to obtain a one-to-one representation, especially for inlets at 90° to the flow, for large, heavy suspended solids.

2) For particles that fall within the Stokes' Law range, consistent, representative samples can be obtained.

3) The geometry of the sampler intake has little effect on the representativeness of the sample.

4) The sample intake velocity should equal or exceed the velocity of the stream being sampled.

Sampler Intake Design

The foregoing suggest certain directions that the design of a sampler intake for storm and combined sewer flows should take. At the outset, it appears unwise to attempt to sample suspended solids that fall much outside the Stokes' Law range. A realistic maximum size for sand with specific gravity of 2.65 would appear to be around 0.1 mm to 0.2 mm. High sample intake velocities will be required, perhaps in excess of 3 m/s (10 fps), if the sample is to be representative.

Although the flow may be nearly homogeneous, except for very coarse solids and large floatables, more than one sample intake is desirable for reliability of operation as well as insurance against some unforeseen gradient in the pollutant. In view of the changing water levels in the conduit with changing flows, the changing velocity gradients within the flows, and the possibility of changing pollutant gradients not only with respect to these but also with type of pollutant; not even a dynamically adaptive sampler intake can be designed to gather a sample that is completely representative in every respect at the same time. In the absence of some consideration arising from the particular installation site, a regular distribution of sampling intakes across the flow, each operating at the same velocity, would appear to suffice. Since the intakes should be as non-invasive as possible in order to minimize the obstruction to the flow and hence the possibility of sewer line blockage, it seems desirable to locate them around the periphery of the conduit.

In order to prevent unwanted material (rocks, sticks, rags, and similar debris) from entering the sampling train and possibly clogging or damaging the equipment, the sampler intake must provide some sort of a screening function. Due to the nature of stormwater and combined sewer flows, a fine mesh screen does not seem desirable. Instead, a screen made up of a number of rather large holes, say 0.3 to 0.6 cm (1/8 to 1/4 in.) in diameter, appears more desirable.

SAMPLE GATHERING SUBSYSTEM

Three basic sample gathering methods or categories can be identified; mechanical, forced flow, and suction lift. Several different commercial samplers using each method are available today. The sample lift requirements of the particular site often play a determining role in the gathering method to be employed.

Mechanical Methods

There are many examples of mechanical gathering methods used in both commercially available and one-of-a-kind samplers. One of the more common designs is the cup on a chain driven by a sprocket drive arrangement. In another design, a cup is lowered within a guide pipe, via a small automatic winch and cable. Other examples include a self closing pipe-like device that extracts a vertical "core" from the flow stream, a specially contoured box assembly with end closures that extracts a short length (plug) of the entire flow cross-section, a revolving or oscillating scoop that traverses the entire flow depth, etc.

Some of the latter units employ scoops that are characterized for use with a particular primary flow measurement device such as a weir or Parshall flume and extract an aliquot volume that is proportional to the flow rate. Another design for mechanically gathering flow proportional samples involves the use of a sort of Dethridge wheel with a sample cup mounted on its periphery. Since the wheel rotation is proportional to flow, the effect is that a fixed volume aliquot is taken each time a certain discharge quantity has passed, and total discharge can be estimated from the size of the resultant composite sample.

The foregoing designs have primarily arisen from one of two basic considerations. First, site conditions that require very high lifts have dictated the use of mechanical gathering units due to the limitations of suction lift pumps and space considerations. Some mechanical units are capable of lifts of 61m (200 ft.) or more. Second, the desire to gather samples that are integrated across the flow depth has led to some of the different mechanical approaches mentioned above. Unless vertical velocity and pollutant gradients are quantified and accounted for, their presence makes the results of such depth integrated samples questionable, at least in a mass discharge sense.

One of the penalties that one must trade-off in selecting a mechanical gathering unit is the necessity for some obstruction to the flow, at least, while the sample is being taken. The tendency for exposed mechanisms to foul, together with the added vulnerability of many moving parts, means that successful operation will require periodic inspection, cleaning, and maintenance.

Forced Flow Methods

All forced flow gathering methods require some obstruction to the flow, but usually it is less than with mechanical gathering methods. It may only be a small inlet chamber with a check valve assembly of some sort or it may be an entire submersible pump. The main advantage of submersible pumps is that their high discharge pressures allow sampling at greater depths, thereby increasing the flexibility of the unit somewhat insofar as site depth is concerned. Pump malfunction and clogging, especially in the sizes often used for samplers, is always a distinct possibility and, because of their location in the flow stream itself, maintenance is much more difficult and costly to perform than on above ground or more easily accessible units. They also necessarily present an obstruction to the flow and are thus in a vulnerable position as regards damage by debris in the flow.

Pneumatic ejection is a forced flow gathering method used by a number of commerical samplers. The gas source required by these units varies from bottled refrigerant to motor driven air compressors. The units that use bottled refrigerant must be of a fairly small scale to avoid an enormous appetite for the gas and, hence, a relatively short operating life before the gas supply is exhausted. Furthermore, concern has recently been expressed about the quantities of freon that are being discharged into the atmosphere. The ability of such units to backflush or purge themselves is also necessarily limited. The advantages of few moving parts, inherent explosion proof construction, and high lift capabilities must be weighed against low or variable line velocities, low or variable sample intake velocities, and relatively small sample capacities in some designs. Another disadvantage of most pneumatic ejection units is that the sample chamber fills immediately upon discharge of the previous sample. Thus, it may not be representative of flow conditions at the time of the next triggering and, if paced by a flowmeter, correlation of results may be quite difficult.

Suction Lift Methods

Suction lift units must be designed to operate in the environment near the flow to be sampled or else their use is limited to a little over 9m (30 ft.) due to atmospheric pressure. Several samplers that take their suction lift

directly from an evacuated sample bottle are available today. Vacuum leaks, the variability of sample size with lift, the requirement for heavy glass sample bottles to withstand the vacuum, difficulty of cleaning due to the requirement for a separate line for each sample bottle, the necessity of placing the sample bottles near the flow stream (and hence in a vulnerable position), the varying velocities as the sample is being withdrawn, etc., are among the many disadvantages of this technique.

Other units are available that use a vacuum pump and some sort of metering chamber to measure the quantity of sample being extracted. These units in some designs offer the advantages of fairly high sample intake and transport velocities, the fluid itself never comes in contact with the pump, and the pump output can easily be reversed to purge the sampling line and intake to help prevent cross-contamination and clogging. Their chief disadvantage, shared with certain other suction lift designs arises from the following consideration.

With all suction lift devices a physical phenomenon must be borne in mind and accounted for if sample representativeness is to be maintained. When the pressure on a liquid (such as sewage) which contains dissolved gases is reduced, the gases will tend to pass out of solution. In so doing they will rise to the surface and entrain suspended solids in route. (In fact, this mechanism is used to treat water; even small units for aquariums are commercially available.) The result of this is that the surface layer of the liquid may be enhanced in suspended solids, and if this layer is a part of a small sample aliquot, the sample may not be at all representative. In the absence of other mitigating factors, the first flow of any suction lift sampler should therefore be returned to waste.

A variety of positive displacement pumps have been used in the design of suction lift samplers, including flexible impeller, progressive cavity rotary screw, roller or vane, and peristaltic types. Generally these pumps are self-priming (as opposed to many centrifugal pumps), but some designs should not be operated dry because of internal wearing of rubbing parts. The desirability of a low-cost pump that is relatively free from clogging has led many designers to use peristaltic pumps. A number of types have been employed including finger, nutating, and two- and three-roller designs using either molded inserts or regular tubing. Most of

these operate at such low flow rates, however, that the representativeness of suspended solids is questionable. Newer high-capacity peristaltic pumps are now available and should find application in larger automatic samplers. The ability of some of these pumps to operate equally well in either direction affords the capability to blow down lines and help remove blockages. Also, they offer no obstruction to the flow since the transport tubing need not be interrupted by the pump, and strings, rags, cigarette filters and the like are passed with ease.

All in all, the suction lift gathering method appears to offer more advantages and flexibility than either of the others for a storm or combined sewer application. The limitation on sample lift can be overcome by designing the pumping portion of the unit so that it can be separated from the rest of the sampler and thus positioned within 6m (20 ft.) or so of the flow to be sampled. For many sites, however, even this will not be necessary.

SAMPLE TRANSPORT SUBSYSTEM

The majority of the commercially available automatic samplers have fairly small line sizes in the sampling train. Such tubes, especially at 0.3 cm (1/8 in.) inside diameter and smaller, are very vulnerable to plugging, clogging due to the build-up of fats, etc. It is also imperative that adequate sample flow rate be maintained throughout the sampling train in order to effectively transport the suspended solids. In horizontal runs the velocity must exceed the scour velocity, while in vertical runs the settling or fall velocity must be exceeded several times to assure adequate transport of solids in the flow.

The complexities inherent in the study of a two-phase mixture such as soil particles and water are such that rigorous analytical solutions have not yet been obtained except in certain limiting cases such as the work of Stokes mentioned earlier. The use of hydraulic size, which is the average rate of fall that a particle would finally attain if falling alone in quiescent distilled water of infinite extent, as a descriptor for a particle involves its volume, shape, and density. It is presently considered to be the most significant measurement of particle size. However, there are no analytical relationships to allow its computation; recourse must be made to experiment.

An excellent discussion of the fundamentals of particle size analysis is given in (6). Table 1, which is taken from data presented therein, illustrates the effect of shape factor on hydraulic size for sand particles with specific gravity of 2.65 in water at 20°C. It can be noted that while a sphere with a nominal diameter of 0.2 mm will fall only about one-third faster than a similar sized particle with a shape factor of 0.3; a sphere with a nominal diameter of 4.0 mm falls over 2-1/2 times faster than a particle with SF=0.3. For curves showing temperature effects, correction tables, etc., the reader is referred to (6).

TABLE 1. EFFECT OF SHAPE FACTOR ON HYDRAULIC SIZE (IN CM/SEC)*

Nominal Diameter (mm)	Shape Factors				
	0.3	0.5	0.7	0.9	Spheres
0.20	1.78	1.94	2.11	2.26	2.43
0.50	4.90	5.63	6.31	7.02	7.68
1.00	8.49	10.10	12.10	14.00	15.60
2.00	12.50	15.50	19.30	23.90	28.60
4.00	17.80	22.40	28.00	35.60	46.90

* Taken from reference 6.

The transport of solid particles by a fluid stream is also an exceedingly complex phenomena, and no complete theory which takes into account all of the parameters has yet been formulated. Empirical formulae exist, however, some of which have a fairly wide range of applicability. An expression for the lowest velocity at which solid particles heavier than water still do not settle out onto the bottom of the pipe of channel has been developed by Knoroz (8) on the basis of numerous experiments carried out under his direction at the All-Union Scientific Research Institute for Hydraulic Engineering.

A somewhat simpler expression for the adequate self-cleaning velocity of sewers derived by Camp from experimental findings of Shields as given in (9) is:

$$V = \sqrt{6.4gd\ (s.g.-1)/f} = \frac{1.486}{n} R^{1/6} \sqrt{0.8d(s.g.-1)} \qquad [4]$$

where f is the friction factor, n is Manning's roughness coefficient, and all other terms are as previously identified. Using equation [4], for example, it is seen that a velocity of 0.6 m/s (2 fps) is required to adequately transport a 0.09 mm particle with a specific gravity of 2.65 and a friction factor of 0.025. By comparison, the fall velocity of such a particle is around 0.06 m/s (0.2 fps).

In summary, the sampling train must be sized so that the smallest opening is large enough to give assurance that plugging or clogging is unlikely in view of the material being sampled. However it is not sufficient to simply make all lines large, which also reduces friction losses, without paying careful attention to the velocity of flow. For a storm or combined sewer application, minimum line sizes of 0.95 to 1.3 cm (3/8 to 1/2 in.) inside diameter and minimum velocities of 0.6 to 0.9 m/s (2 to 3 fps) would appear warranted. Finally, sharp bends and twists or kinks in the sampling line should be avoided if there is any possibility of trash or debris in the sample that could become lodged and restrict or choke the flow. The same is true of valve designs. It also appears desirable to deliver the sample under pressure all the way from the pump to the sample container to further help reduce clogging.

SAMPLE STORAGE SUBSYSTEM

For storm and combined sewer applications, discrete sampling is generally desired. This allows characterization of the sewage throughout the time history of the storm event. If the samples are sufficiently large, manual compositing can be performed based on flow records or some other suitable weighting scheme. Although the quantity of samples required will be a function of the subsequent analyses that are to be performed, in general at least 1 liter and preferably 2 liters will be desired. An additional benefit arises because such relatively large samples are less vulnerable to errors arising from cross-contamination.

The sample container itself should either be easy to clean or disposable. The cost of cleaning and sterilizing makes disposable containers attractive, especially if bacteriological analyses are to be performed. Although some of today's better plastics are much lighter than glass and can be autoclaved, they are not so easy to clean or inspect for cleanliness. Also, the plastics will tend to scratch more easily than glass and, consequently, cleaning a well-used container can become quite a chore. The food packaging industry, especially dairy products, offers a wide assortment of potential disposable sample containers in the larger sizes. Both the 1.9ℓ (1/2 gal.) paper and plastic milk cartons can be considered viable candidates, and their cost in quantity is in the pennies-each range.

The requirements for sample preservation are enumerated in (10) and will not be repeated here except to note that refrigeration is stated as the best single preservation and will, in all likelihood, be required unless the sampling cycle is brief and samples are retrieved shortly after being taken. It should be mentioned, however, that if the samples are allowed to become too cold, they may no longer be representative. For example, destruction of the organisms necessary for the development of BOD may occur, or freezing may cause serious changes in the concentration of suspended solids. Light can also affect samples and either a dark storage area or opaque containers would seem desirable. Unless disposable containers are used, however, it will be difficult to inspect an opaque container for cleanliness. Again the paper milk carton is attractive since not only is it relatively opaque, but its top opens completely allowing visual inspection of its contents.

CONTROLS AND POWER SUBSYSTEM

The control aspects of some commercial automatic samplers have come under particular criticism as typified by comments reported in (1). It is no simple matter, however, to provide great flexibility in operation of a unit while at the same time avoiding all complexities in its control system. The problem is not only one of component selection but packaging as well. For instance, even though the possibility of immersion may be extremely remote in a particular installation, the corrosive highly-humid atmosphere which will, in all likelihood, be present makes sealing of control elements and electronics desirable in most instances.

The automatic sampler for storm and combined sewer application will, in all likelihood, be used in an intermittent mode; i.e., it will be idle for some period of time and activated to capture a particular meteorological event. If field experience to date is any indication, the greatest need for an improved control element is for an automatic starter. While the sensor is not a part of the sampler proper, its proper function is essential to successful sampler utilization. Although remote rain gages, etc., can be used for sensing elements, one of the most attractive techniques would be to use the liquid height (or its rate of increase) to start a sampling cycle. This will avoid the difficulties associated with different run-off times due to local conditions such as dryness of ground, etc.

The controls determine the flexibility of operation of the sampler, its ability to be paced by various types of flow measuring devices, etc. Built-in timers should be repeatable and time periods should not be affected by voltage variations. The ability to repeatedly gather the required aliquot volume independent of flow depth or lift is very important if composite samples are to be collected. Provisions for manual operation and testing are desirable as is a clearly laid out control panel. Some means of determining the time when discrete samples were taken is necessary if synchronization with flow records is contemplated. An event marker could be desirable for a sampler that is to be paced by an external flow recorder. Reliability of the control system can dominate the total system reliability. At the same time, this element will, in all likelihood, be the most difficult to repair and calibrate. Furthermore, environmental effects will be the most pronounced in the control system.

The above tasks can probably be best executed, in the light of the current electronics state-of-the-art, by a solid state controller element. The unit should be of modular construction for ease of modification, performance monitoring, fault location, and replacement/repair. Such an approach also lends itself to encapsulation which will minimize environmental effects. Furthermore, solid state controllers can be easily designed with sufficient flexibility to accept start commands from a variety of types of remote sensors, telephone circuits, etc. Finally, one of the attributes essential to the control system of an automatic sampler to be used in a storm or combined sewer application is that it be able to withstand power outages and continue its program. Such power interruptions appear to be increasingly common as demand for electricity continues to grow.

The foregoing discussion as it relates to problems associated with interruptions in electrical service is, of course, directed to samplers that rely upon outside power for some aspect of their operation. The need for high sample intake and transport velocities, larger sample lines and capacities, together with the possible requirement for mechanical refrigeration make it unlikely that such a sampler can be totally battery operated today. Other approaches to self-contained power such as custom designed wet-cell packs, diesel generators, etc., while within the current state-of-the art, introduce other problems and complexities that must be carefully weighed before serious consideration can be given to their incorporation in an automatic sampler design.

SECTION V

DESIGN IMPLEMENTATION

GENERAL

From the foregoing discussion, it can be seen that it is indeed a formidable task to design a single piece of equipment that is eminently suitable for all storm and combined sewer applications. For this reason, a functional module approach was taken in the design of a prototype automatic sewer sampling system aimed at overcoming deficiencies or inadequacies in much of the extant equipment. Using this building block type approach, wastewater samplers can be assembled from basic system components, but tailored for a particular installation or program.

The intention was not to develop a "finished" design that was production engineered and ready for quantity manufacturing but, rather, to embody as many desirable features and incorporate as many new technologies as possible, in order to be able to assess whether or not the anticipated benefits had, in fact, been realized. Consideration was given to ultimate producibility, however, in that cost considerations were heavily weighed. For example, a pumping system that appeared attractive in many respects was rejected because of its nearly $1,500 cost. Even given quantity and original equipment manufacturer (OEM) discounts, it was felt that the price could never be reduced to a practicable level. Similar considerations were obtained in the design of the control subsystem. The near revolution in cost and availability of digital integrated circuit devices was anticipated at the time of the design (mid 1973), but implementation techniques available today were not obtainable at that time. Functionally, however, the control subsystem can be essentially duplicated today in a much more compact package. It might not be necessary to incorporate all the provisions for adjustment that were felt desirable for the prototype in a production model, however.

The various elements of the prototype automatic sewer sampling system are schematically indicated in figure 6. Each of the functional subsystems identified in Section IV will be discussed in turn as implemented in the prototype unit.

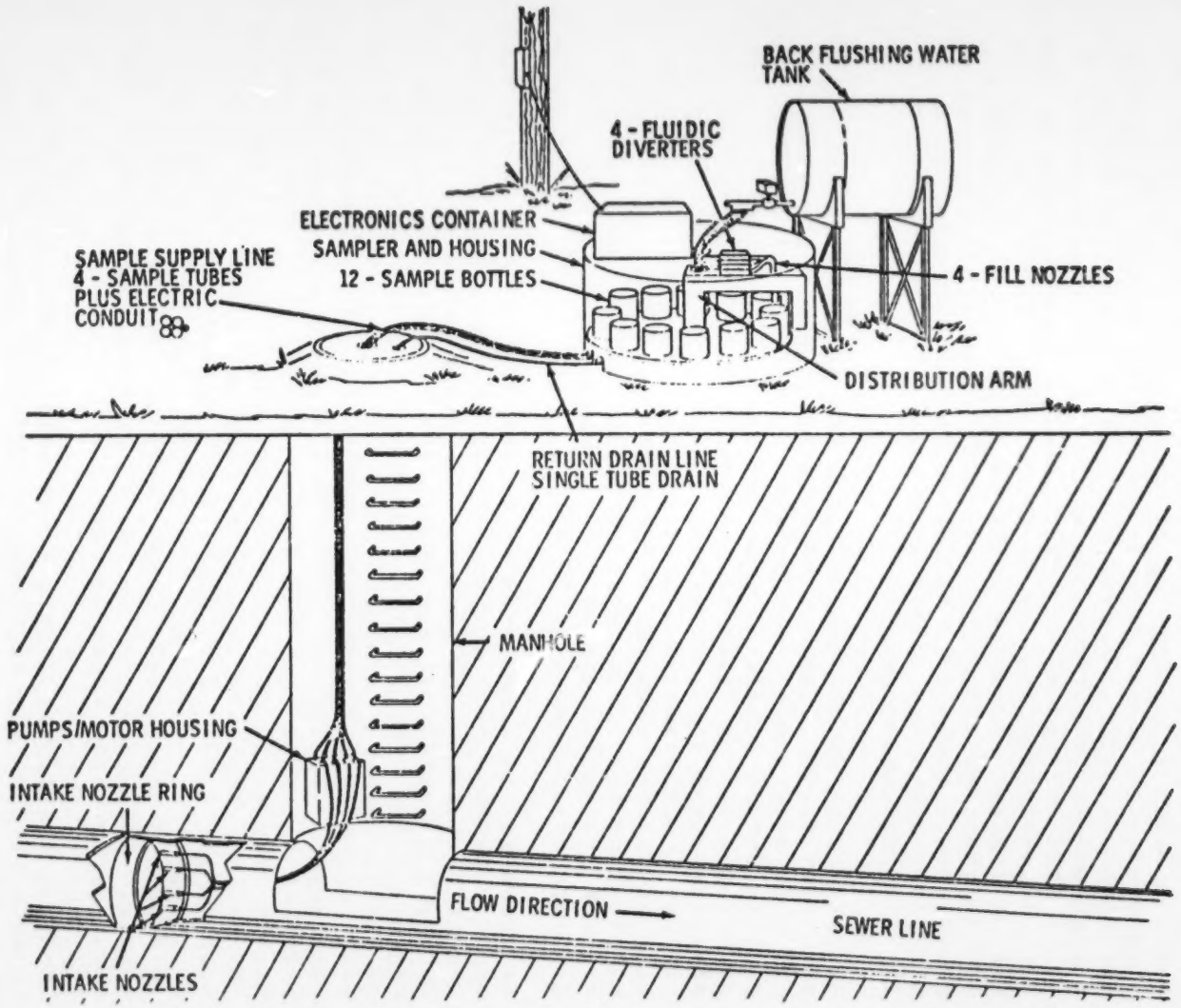


Figure 6. Prototype Automatic Sewer Sampling System Schematic

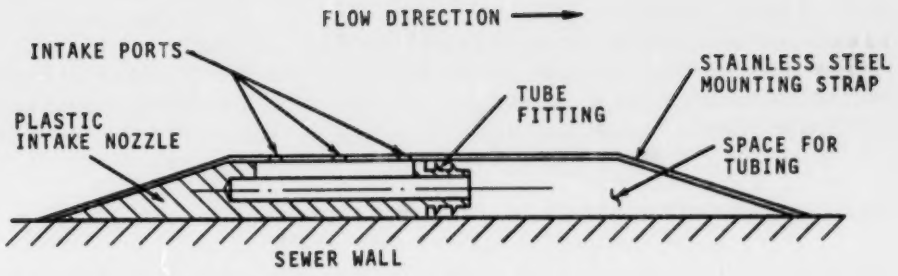
SAMPLER INTAKE SUBSYSTEM

Due to the virtual mandate that there be no rigid obstruction to the flow in view of the very large solids that are often encountered, the prototype sampler intake for use in smaller sewer pipes, say up to 1.5m (5 ft) in diameter, is comprised of a number of nozzles located around the circumferential periphery of the pipe. Because of the modular design of the prototype system, the actual number of intakes employed can be varied depending upon the size of the pipe in which the sampler is to be used. The use of a number of discrete intake nozzles is to allow for redundancy in the event of clogging of an individual nozzle by rags, paper, etc., and also contributes to the gathering of a more representative sample when vertical stratification of the flow is encountered.

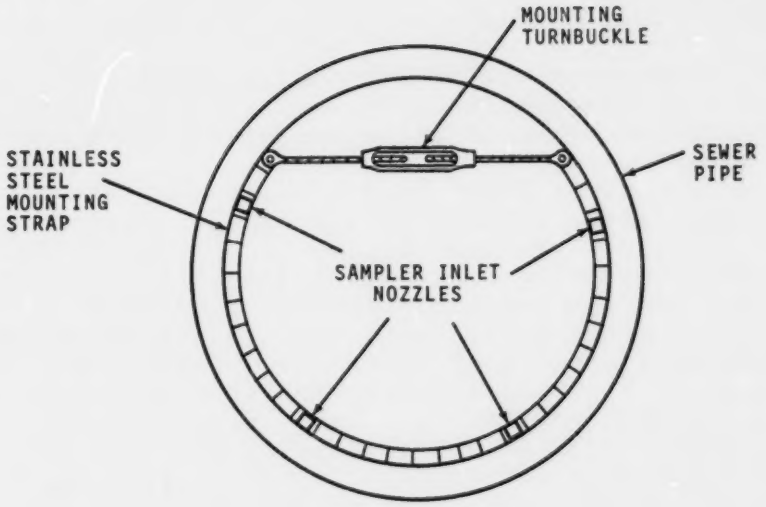
The prototype intake was designed for installation in a nominal 0.6m (2 ft) diameter sewer pipe of arbitrary material. For this size range, four intake nozzles were provided. Each plastic intake nozzle (figure 7a) has a slot which is aligned with three 0.5 cm (3/16 in.) diameter holes or ports in the mounting strap that are spaced linearly in the direction of the flow. These serve a preliminary screening function to keep out large, unwanted solids such as stones that might possibly damage other portions of the unit. The four intake nozzles are spaced around the periphery, two on each side of the pipe as indicated in figure 7b.

As shown in the schematics of figure 7, the 30.5 cm (12 in.) wide stainless steel mounting strap encloses the nozzles and intake tubing to help protect them from damage due to the movement of solids in the flow. The leading and trailing edges are split back for 7.6 cm (3 in.) and bent down slightly, forming "fingers" that contact the inside wall of the sewer pipe and grip it securely when the turnbuckle is tightened. The intake lines are routed to and along the crown of the pipe into the manhole area. The "ring" formed by the sampler intake projects less than 2.5 cm (1 in.) from the wall of the pipe and, thus, does not offer undue resistance to the flow. The intake would normally be mounted approximately 0.6-0.9m (2-3 ft) up the pipe from the manhole in the direction of the flow. This can be accomplished by a single technician in 15 minutes or less, thus, minimizing the need for flow interruption.

For installation in larger rectangular conduits, especially those with open top sections, a different mounting arrangement would be desired. Cylindrical plastic intake screens



7a. Cross Section through an Intake Nozzle



7b. Installation Schematic

Figure 7. Prototype Sampler Intake Schematic

perforated with a large number of 0.5 cm (3/16 in.) holes could be used on the end of each intake line. When mounted on a rod hinged to a tethered float (the pump box could be used for this purpose) and extending at an angle to the channel floor (figure 8), samples could be taken at constant percentages of depth regardless of flow level. Alternately, the intake screens could be weighted and suspended by the tubing at appropriate depths. In either scheme, the intake is free to swing away if struck by a solid object in the flow, which will minimize damage possibilities.

SAMPLE GATHERING SUBSYSTEM

The suction lift gathering method was chosen for the prototype automatic sewer sampling system. Among the features wanted in the pump were a self-priming capability; the ability to operate dry without damage; the ability to operate either forward or reverse to allow for pressurized backflushing and blowdown; the ability to pass strings, papers, cigarette filters, etc., with ease; and a minimum inside diameter of around 1 cm (3/8 in.).

The foregoing requirements led to the further investigation of peristaltic pumps in the larger sizes. The principal requirement was a capacity of at least 7.6 ℓpm (2 gpm) to assure adequate sample intake and transport velocities.

Although not strictly a peristaltic tubing pump, the Vanton flex-i-liner sealless plastic pump was also given preliminary consideration. In this valveless unit, which avoids the use of gaskets, pumping is accomplished by a rotor, mounted on an eccentric shaft, which rotates within a liner creating a progressive squeeze action on the fluid trapped between the liner and the body block. Thus, the only two parts in contact with the fluid being pumped are the outer surface of the low cost moulded flexible liner and the inner surface of the plastic body block. Both of these components are available in a variety of materials. This pump's action resembles that of a single-lobed peristaltic pump with a very oblong moulded tube inside. Cost and high power requirements, e.g. a 375W (1/2 HP) motor is required for a single pump capable of delivering 7.6 ℓpm (2 gpm) against a 2.5 kg/sq cm (36 psi) head, led to dropping this unit from further consideration, but the concept is available in models that deliver up to 151 ℓpm (40 gpm).

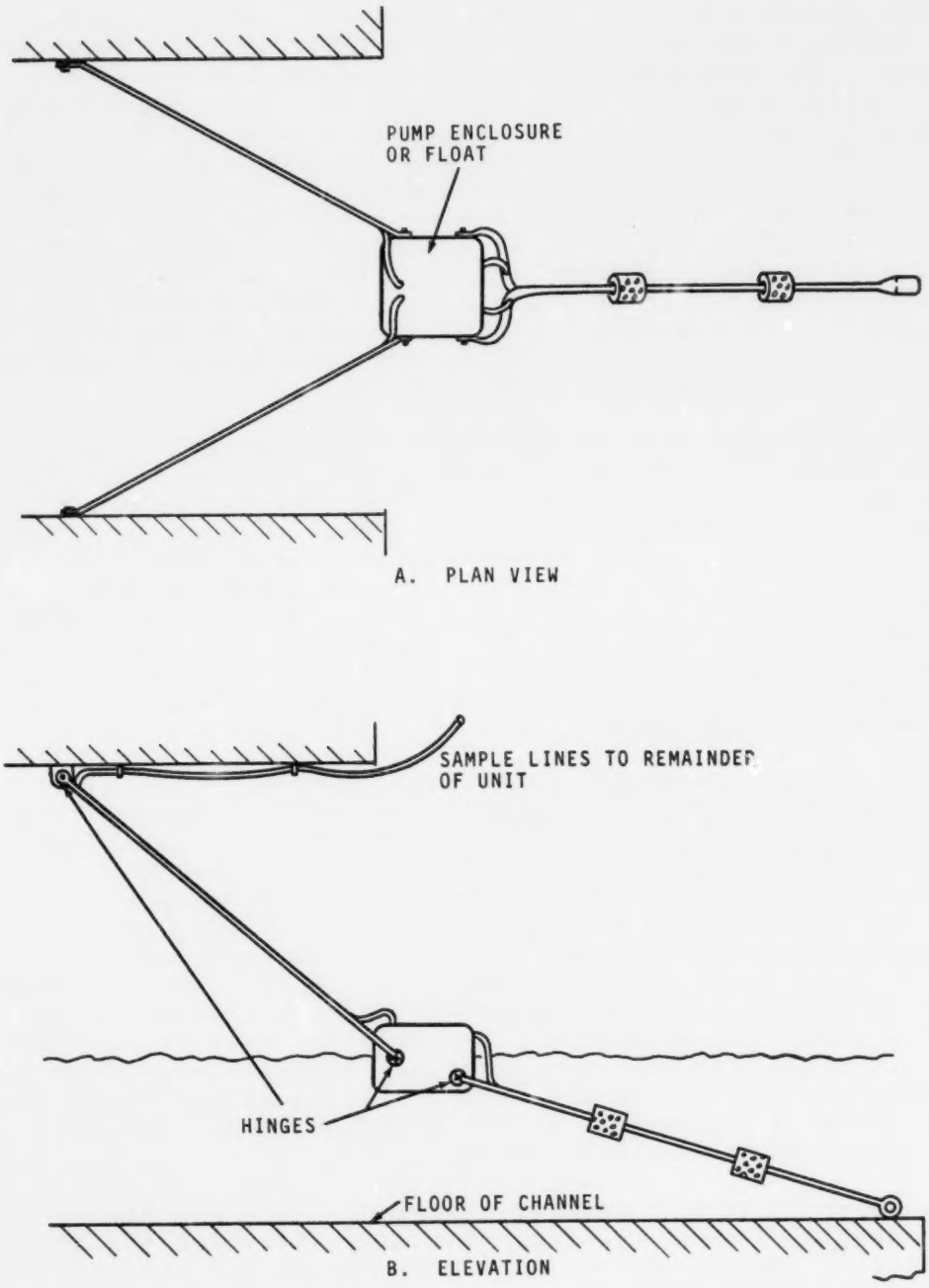


Figure 8. Alternate Sampler Intake Schematic for Large Channels

There are a number of types of peristaltic pumps available on the market including finger, nutating, and two- and three-roller designs using either moulded inserts or regular tubing. The nutating type was eliminated because of its typical low flow rate (1.5 ℓpm maximum). Finger type pumps were given more serious consideration in view of the capability of some designs to handle up to four tubes simultaneously. In order to obtain the desired flow rate, however, it is necessary to use tubing with a minimum inside diameter of 1.9 cm (3/4 in.). This is undesirable because of the desire to minimize changes in line size, and flow velocities in such large tubes are inadequate to assure good solids transport. Furthermore, these large units are expensive (from $450 to over $1,200, depending upon features) and require large motors, e.g. 525W (3/4 HP).

A number of two-rotor designs were investigated. Some of these are now available in large sizes, e.g. up to 78 ℓpm (21 gpm), but are priced from $375 to $565 per head without motor. The alternative is to use a smaller pump at a higher rotational speed. Such pump heads cost less than $100. A typical unit was extensively tested and found to be generally satisfactory with two exceptions. First, the flow was highly pulsating, and when the intake line was deliberately plugged, rather violent motions resulted. Second, and even more important, tubing life was quite short (e.g., 6-8 hours) for all but small lifts.

During the course of the pump investigation, a new high-capacity three-rotor peristaltic pump was introduced. Until that time, all three-rotor designs had been of insufficient capacity to warrant serious consideration. One of these units was extensively tested and found to be very satisfactory in all regards. The pump easily passed such deliberately introduced debris as cigarette filters, string, paper, rope, rags, etc. It was possible to clog the intake line by packing it with paper toweling and compacting it with a steel rod while the pump was off. When run in the forward direction, the pump was unable to dislodge such an artificial plug (ultimately the tubing would collapse), but when operated in reverse in the backflush mode, the pump was always able to clear the line.

Based upon favorable testing experience, the quality of workmanship, favorable design features including the ability to "stack" pump heads, and low cost (under $70 per head), the decision was made to utilize this pump in the prototype design. The four pump heads used in the prototype were

especially built for this application by the manufacturer, the nonstandard feature being the staggered alignment of shaft keys and rotors of the respective heads so that the load from each head would be more evenly distributed as seen by the motor. After considerable experience with the prototype, it is not felt that this latter sophistication is necessary.

These pump heads are rated at approximately 9.5 ℓpm (2.5 gpm) at their normal operating speed of approximately 600 rpm. They use 1 cm (3/8 in.) inside diameter tubing with a 1/3 cm (1/8 in.) thick wall. Experience to date has indicated that, even with this high capacity operation, tubing life on the order of 30 to 40 hours can be expected. It requires less than 30 minutes to change the tubing in the present design, and so the standard maintenance procedure is to install fresh tubing after 20 hours of pump operation. This corresponds to some 20 storm events.

The pump heads are driven through common keyed shafts which eliminate all requirements for interconnecting gears, pulleys, etc. Although the prototype unit uses four sample lines, this number can be increased or decreased simply by adding or deleting pump heads. The pumps are driven by an inexpensive 250 watt (1/3 horsepower) electric motor through a simple V-belt drive. They are completely enclosed in a sealed plastic box that can withstand immersion without leaking. Marine connectors and fittings have been used throughout. This means that the pumps and motor can be located near the actual flow to be sampled and operate even though the sewer becomes surcharged or flooded. As a protective measure, a liquid level sensor has been included inside the pump/motor housing. It will automatically shut the system off should liquid begin to accumulate inside the housing due to pump tubing failure or a leak due to housing damage. The general equipment arrangement inside the housing is shown in figure 9 (the plastic cover is removed). The anodized aluminum mounting plate serves as a heat exchanger as well as the main structural member of the housing. A small "muffin" fan provides air circulation over the plate and motor, resulting in quite acceptable ambient temperatures within the sealed box.

SAMPLE TRANSPORT SUBSYSTEM

The sample transport subsystem of the prototype sampler consists of four identical but discrete sample trains. Each begins with a flexible Tygon tube connected to the intake

at one end and the pump housing at the other. Since the pump housing is located very close to the flow to be sampled, these suction lines are relatively short. Inside the pump housing, 0.95 cm (3/8 in.) I.D. silicone tubing with a 0.32 cm (1/8 in.) thick wall is used. These lines are approximately 0.6m (2 ft) long. The connecting lines between the pump housing and the sample distribution arm are 1.3 cm (1/2 in.) I.D. Both semi-flexible PVC pipe (for longer runs) and tygon tubing (for relatively short runs) have been successfully used for this purpose, depending upon the test site conditions. This is the maximum recommended size in order to keep sample transport velocities high enough, over 1.2 mps (4 fps) at the 10 ℓpm (2.5 gpm) pumping rate, to assure adequate transport of all suspended solids.

In order to allow for backflushing to minimize cross-contamination of samples and to help dislodge any matter that might be blocking an intake nozzle, a fresh water tank is connected via a solenoid valve and manifold (figure 10) to each sample line. A 208ℓ (55 gal) drum is used for this purpose and is mounted on a stand above the sample distribution arm. A check valve in each line assures that the fluidic diverters will function when some lines are not flowing full due to lower water levels in the sewer or partial blockages, and provides a redundant assurance that sewage cannot be pumped into the fresh water tank should the solenoid valve malfunction.

In order to minimize the possibility of clogging or malfunction due to strings, etc., in the flow, fluidic diverters were custom designed to avoid the necessity of using valves or other moving parts in the sample lines. Functionally, the fluidic diverters allow the pump flow normally to be returned to waste. When a sample is to be taken, the diverters are automatically switched to fill the sample cup. This is accomplished by using a small solenoid-operated air valve to control aspiration of the fluidic diverter control ports. These are illustrated in figure 11.

Short sections of Tygon tubing are used at the discharge side of the fluidic diverters. The biased side (normally return to waste) lines lead to a manifold block on the distribution arm, from which a single, large tube carries the flow back to the sewer. The lines from the sample side of the fluidic diverters are held by the distribution arm so that on signal they will discharge directly into the next sample container.

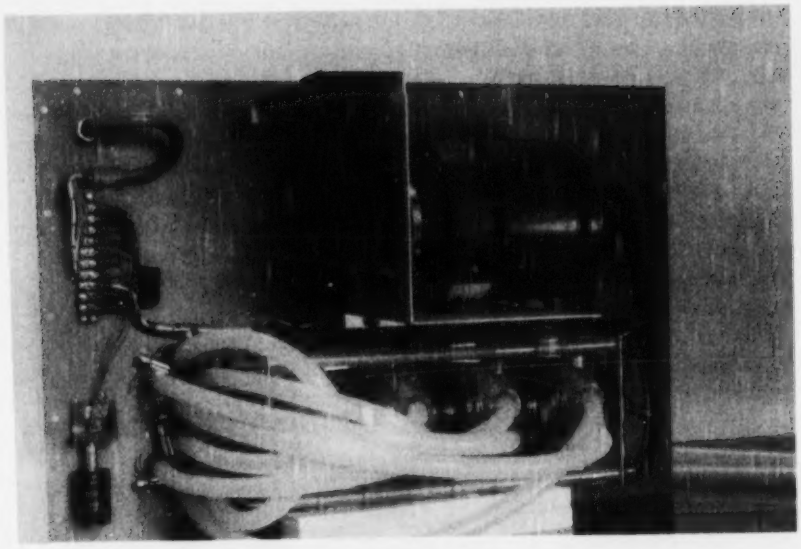


Figure 9. General Equipment Arrangement Inside the Pump Housing

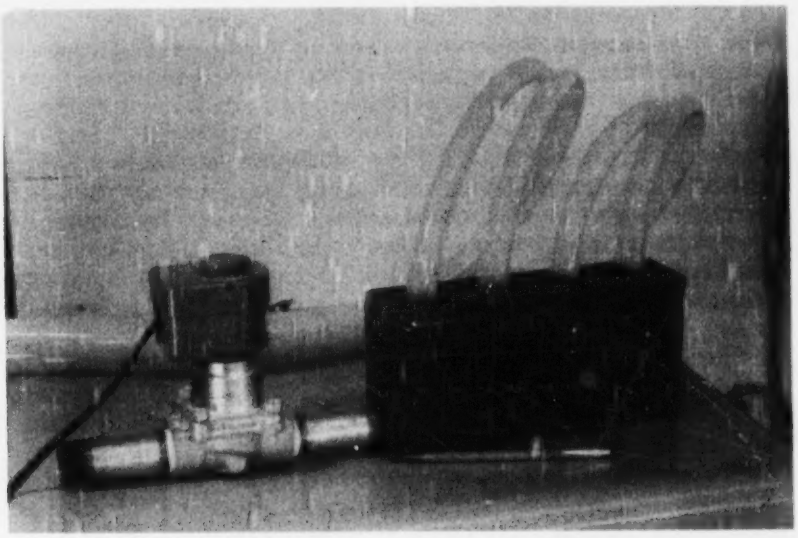
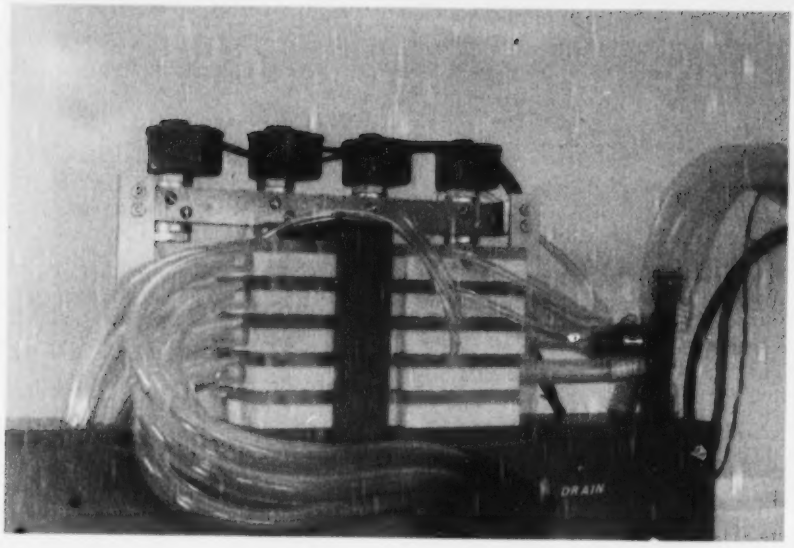


Figure 10. Backflush Water Solenoid Valve and Check Valve Manifold



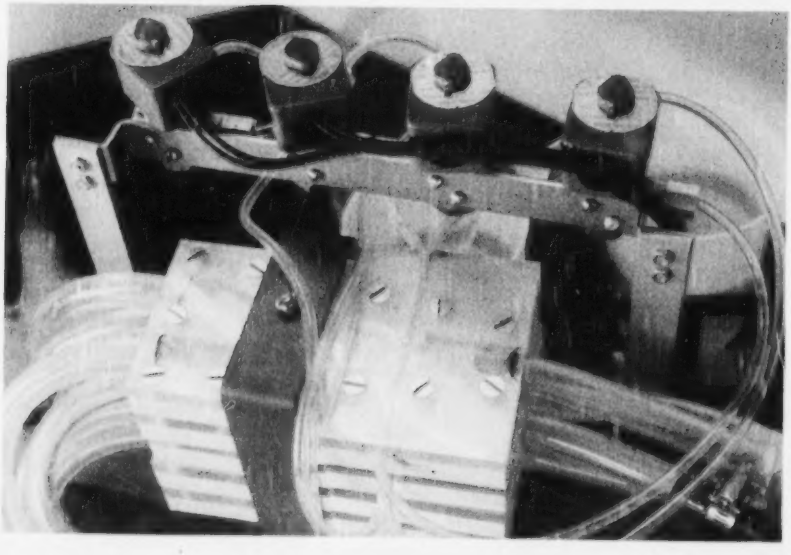


Figure 11. Fluidic Diverters and Air Control Valves

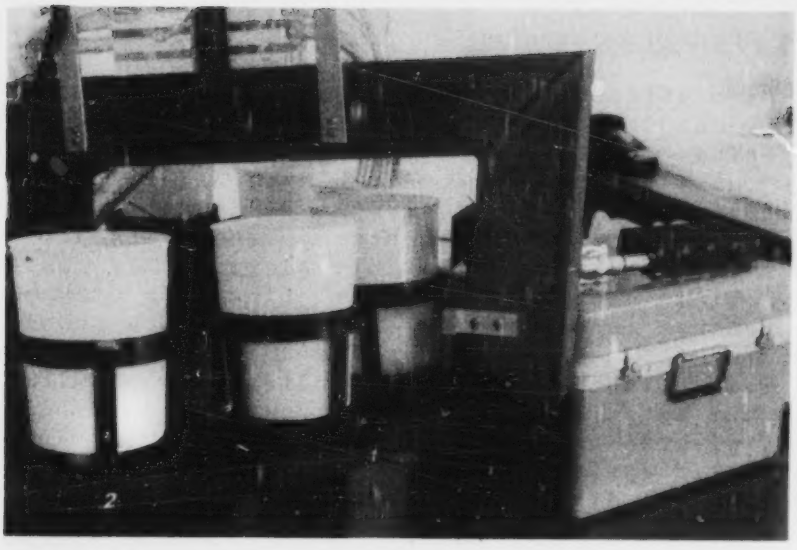
Sample Storage Subsystem

For characterization of storm and combined sewer flows, discrete sampling is almost mandatory. In order to provide a sufficient quantity of sample for a rather complete laboratory analysis, the equipment has been designed to provide approximately 2ℓ (1/2 gal) samples. Since there are a number of individual lines each operating independently, varying flow stages and possible plugging may result in one or more lines not containing full flow. In view of this, a provision was incorporated for weighing each sample container to assure that the desired amount of sample had, in fact, been taken. This is accomplished by mounting each sample cup in an individual counterweighted arm (figure 12) that is pivoted near its middle. A tab on the arm contacts a cantilever spring connected to a limit switch which is mounted on the distribution arm. When a precalibrated quantity of sample has been gathered in the cup, the weight of the fluid overcomes the spring tension, thereby closing the limit switch which causes the fluidic diverter to switch the flow back to waste.

The fluidic diverters and discharge lines are located on a distribution arm that rotates 350° to fill the 12 sample cups. This rotation is accomplished via a small electric motor and friction drive wheel (figure 13). After filling the twelfth cup, the arm contacts a limit switch that shuts the entire system down until manually reset by an operator. The sample containers themselves are 2.5ℓ (84 oz) disposable plastic cups with leakproof snap-on lids. These have a panel that allows field annotations to be written with almost any writing instrument including pencil, ballpoint or felt tip pens, etc.

Controls and Power Subsystem

Completely solid-state electronic control elements have been used throughout in the prototype design. They are housed within a weather-proof case (figure 14), which also contains an isolation transformer to preclude any possible shock hazard while working in the sewer with the pump motor. Controls are adjustable in all aspects of the operation, and logic sequences are protected against upset due to power outages. The design will accept an automatic start command from a suitable external sensor. The unit is designed to be paced by its built-in timer, but may also be paced by an



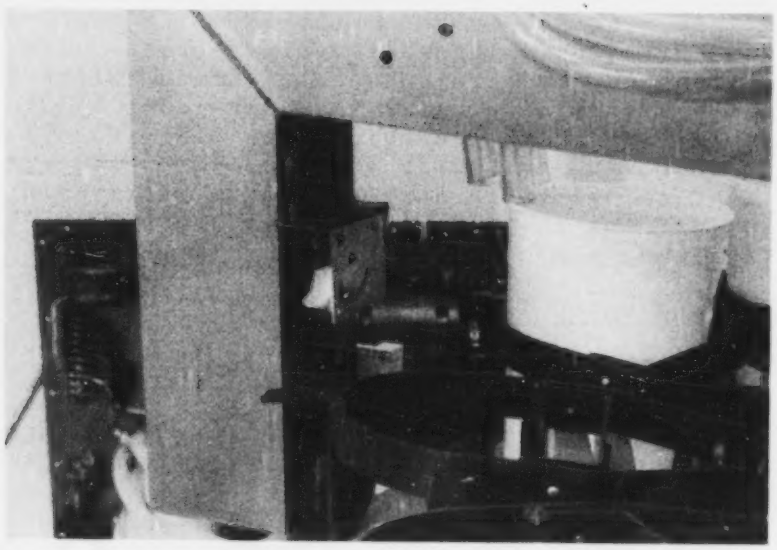


Figure 12. Views of Sample Cup Mounting And Weighing Control

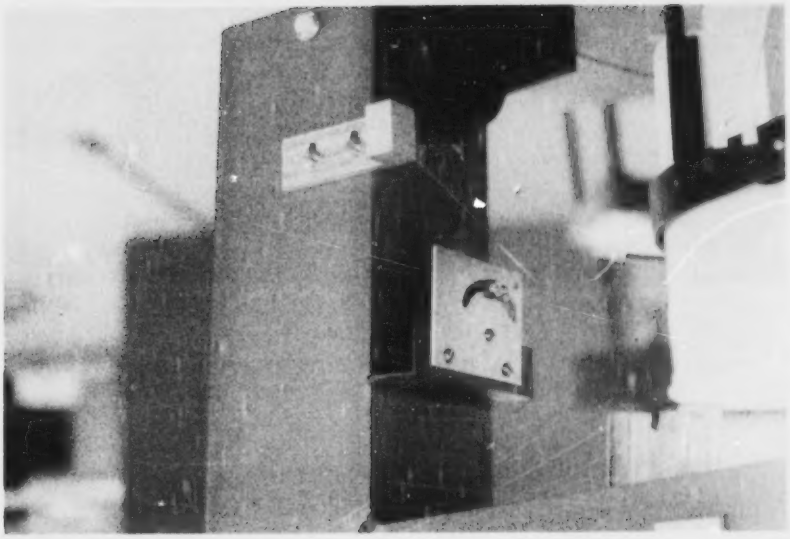
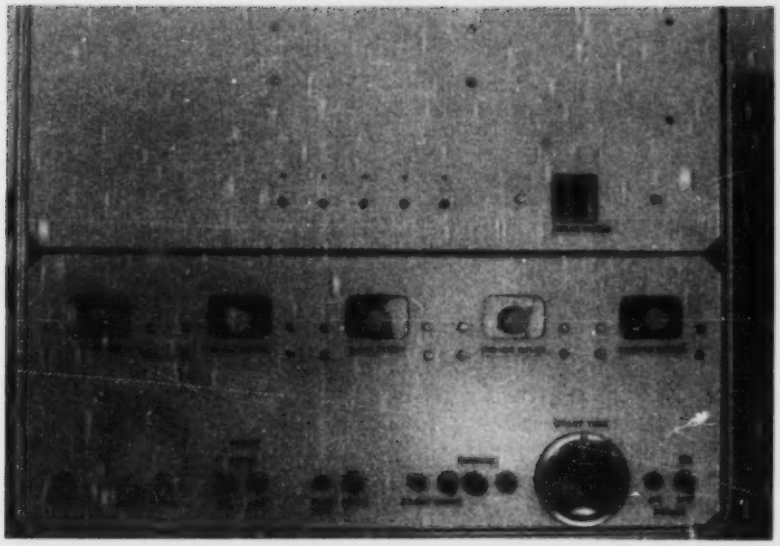


Figure 13. Distribution Arm Drive Wheel



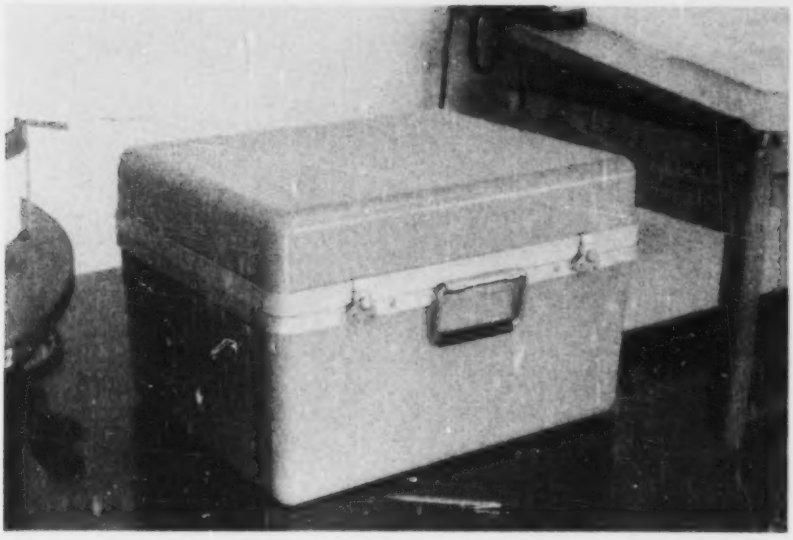


Figure 14. Electronic Control Panel and Case

external flowmeter where one is available. A clock is included in the design to allow time synchronization with flow records where desired. One-hundred-ten volt AC electrical power is required to operate the unit. The actual set up, programming, and operation of the unit are described in Section VI.

SECTION VI
INSTALLATION AND OPERATION

INSTALLATION

The sample intake ring is made of stainless sheet steel and sized to fit a 61 cm (24 in.) diameter sewer line. Its diameter can be adjusted by two stainless steel turnbuckles to make it fit securely inside the sewer pipe. Four intakes, positioned between the upstream and downstream ramps of the ring, are connected to the pump enclosure through hoses that are routed to the uppermost point of the ring and along the top of the sewer line to the manhole area. The pump enclosure, although watertight, should be located and secured above the normal high water level if possible (to prevent buffeting damage) and oriented within 10° of level. However, this enclosure should not be placed at an elevation greater than 4.6m (15 ft) above the lowest intake. Use hose clamps on all tubing connections.

Route the four output tubes and the pump motor electrical cable from the pump enclosure to the table set-up location, and attach the tubes to the diverter connections and the electrical cable to the control box. Connect the drain return tube to the table and to prevent kinks or any severe flow restrictions, carefully route it back to the sewer. Locate the freshwater flush tank between 0.9 and 1.5m (3 and 5 ft) above the elevation of the top of the sample distribution arm and fill with water. The electrically operated stop valve and four check valves are attached thereto. Route the four flush lines to the "T" connections in the diverter lines avoiding sagging places where water could settle. Connect the stop valve electrical cable to the control box. Place the sample table such that it is within 2° of level. If necessary, to avoid kinking the drain line, elevate the table several inches by placing blocks under the three support legs. Connect the electrical leads to the control box. Place sample containers in the twelve basket containers and manually lift slightly and rotate the arm such that the four sample tube outlets are over the No. 1 container. Connect the control box power cable to 110 VAC. The system is now ready for automatic or manual sampling as described in the following paragraphs.

AUTOMATIC LIQUID SAMPLING SYSTEM OPERATION

Timing Overview

In operation, the system generally performs as follows. The initial conditions are:

1. Sample bottles empty and in place.
2. Distribution arm set in position number 1.
3. Backflush tank full.
4. All components interconnected and checked out (ready light on).

Upon signal, the sampling sequence begins with the pump turned on in the reverse mode to provide a blow-down that will force any fluid in the lines out through the intake nozzles to clear the sampling train of any possible blockages, previous samples, and/or backflush water. After a predetermined (0-60 seconds) time period, the pump is momentarily stopped and then started in the forward direction. The pump is now extracting sewage from the flow, pumping it through the diverters on the distribution arm, and returning the fluid to waste through the drain provided. After a preset time (0-5 minutes), which is selected to assure that a representative flow is passing through the diverter, the diverter is switched to the sample position and its output flows directly into the sample container. When a predetermined weight of sample (up to 2 liters) has been collected, a switch closes and the diverter redirects the flow to waste. As a backup measure, in the event of a blockage or some other flow restriction, the diverter is also returned to waste at the end of a predetermined time period. This is simply to ensure that the system does not hang up trying to fill one particular sample container.

Two events now occur in parallel. In the first, the backflush valve is opened and, after a momentary dwell, the pump is started in the reverse direction. This allows the complete sampling train to be backflushed for a preset time period to purge the lines of sewage and dislodge any possible blockage that may have occurred. At the end of this predetermined time period (0-60 seconds), the pump will turn off and the freshwater valve will close.

In the second event, the index motor will move the distribution arm assembly to the next sample container position to be ready for the next cycle, which is a repeat of the above sequence. After the twelfth sample container has been

filled, a switch will shut the complete system off, and it will no longer function until the system has once again been initialized.

Timing Sequence

The timing diagram shown in figure 15 indicates the logic operation of the system. Each element is explained in the following discussion. There are manual overrides and manual switch controls which allow for system initialization and for exercising the system in whatever manner may be desired for testing. Certain simple precautions must be taken during the initialization in that some timed events include other events and, if the events are timed too low, they will not occur, e.g., if the PT-2 timer is set too high and the diverter timer is set too low, a sample will not be obtained because the PT-2 time will shadow the diverter time and the diverter will never switch.

Sample Interval - The total sample time includes the time, T1, set on the Sample Timer, CT-1 (0-15 minutes) and the time, T2, set on the Cycle Timer, CT-2 (.016 sec-9 hours). The total time between samples can be adjusted to approximately 9 hours.

Pump Motor - The pump motor is turned on momentarily, T3, in reverse by the Blow-Down Timer, PT-2 (0-60 sec); when the Blow-Down Timer de-energizes, the motor will stop for a period of time, T7, set by the Motor Delay Timer (0-10 sec). The off time set by the Delay Timer is to allow the fields in the motor to collapse with power off. At the end of the delay time the motor will start in the forward direction. The motor will pump forward until CT-1 times out; then after the delay time, T7, determined by the Delay Timer it will reverse and backflush the system with fresh water until the Back-Flush Timer, PT-1 (0-60 sec) times out.

Blow-Down Timer - The Blow-Down Timer is used to reverse the pump to purge the intake lines of remaining fresh water and any sewer liquid or blockage that might be in the sample lines as well as to dislodge material which may be blocking intake orifices.

Back-Flush Timer - The Back-Flush Timer reverses the motor and opens the freshwater flush valve after the Sample Timer times out. It controls the back flush time after the sample has been taken.

Diverter Timer - The Diverter Timer (0-5 minutes) is used to switch the output of the diverter from the drain position to

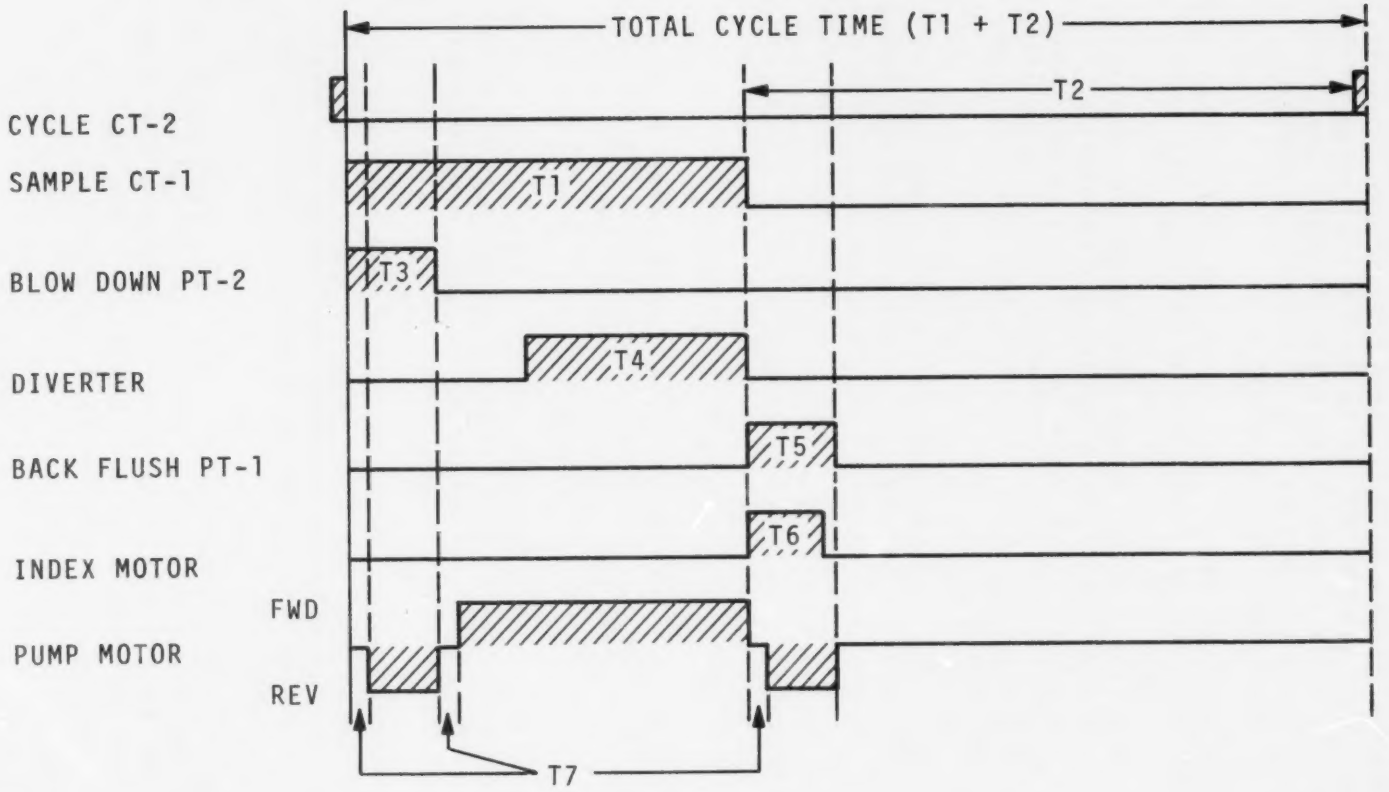


Figure 15. Timing Diagram

the sample position when a representative sample flow has been obtained. When the sample container is filled, as determined by sample weight, the diverter is returned to the drain position. If the container is not filled when CT-1 times out, as might be the case when all intakes are above the fluid level in the sewer or all intakes are blocked, the diverter is also switched to drain.

Flush Valve - The Flush Valve is on the freshwater tank and is opened by PT-1 to allow fresh water to purge the system.

Index Motor - The index motor moves the index arm assembly from one sample position to the next in approximately 13 seconds. This time is not adjustable. The index motor will turn on when CT-1 times out and moves the arm to the next position where it stops. After the twelfth position, the automatic cycling will stop.

Timer Adjustment - The initial set up of the Sample Cycle Timer must allow sufficient time to ensure that a representative sample will be collected. This time must include the time required to blow-down the lines, to stop the pump motor, and to reverse its rotation direction so that it will pump a sample from the sewer. This time should also be long enough so that a sample container will be filled if only one line is collecting a sample.

The Blow-Down Timer and the Motor Delay Timer must be set for a time period that is less than the Diverter Timer time period so that the pumps are pumping samples through the diverters before they are switched to the sample containers.

The Diverter Timer should be adjusted to a time long enough to allow the Blow-Down and motor change of direction to occur, and short enough to enable it to collect a sample before the Sample Cycle Timer times out.

The Back-Flush Timer plus the Motor Delay Timer should be adjusted for a total time of less than 13 seconds. If the total time is greater than 13 seconds, the index arm will pass the next position and there will not be a sample collected for that position.

The Delay Cycle Timer may be set for any time desired from 1 minute to 9 hours; however, the minimum time must be greater than the Back-Flush time plus the Motor Delay time to allow the previous cycle to be completed. The Delay Cycle Time determines the time between samples.

Typical Timer Settings

T1 - 45 seconds

T2 - 1 hour

T3 - 10 seconds

T4 - 20 seconds

T5 - 10 seconds

T6 - 13 seconds (nonadjustable)

T7 - 2 seconds

At the start of a series of samples, and prior to automatic enabling of the system, the system should be manually backflushed with fresh water to clear the lines of any possible blockage.

Manual Mode Operation

The following steps will manually operate the system:

1. Power switch on.
2. Push power trip button twice (light on).
3. Using index motor switch, visually position four sample hoses directly over a container.
4. Pump control right switch to reverse position.
5. Pump control left switch to on position.
6. Flush valve switch to full on position (up).
7. Wait approximately 10 seconds then place flush valve switch to full down position.
8. Place pump control left switch to auto position.
9. Place pump control right switch to auto position.
10. Place pump control left switch to on position.
11. Wait approximately 10 seconds then hold diverter switch in on position until desired

sample quantity is collected in container. Release diverter switch.

12. Place pump control left switch in auto position.

13. Repeat steps 4 through 9.

14. Turn power switch to off position.

System has completed one cycle and is ready to be set up in manual or automatic modes.

Automatic Mode Start-Up Sequence

The following steps will manually start an automatic twelve-sample sequence:

1. Set up timing typically as indicated earlier.

2. Power on.

3. Push power trip button twice (light on).

4. Reset (ready light on).

5. Perform operations 4 through 9 as above.

6. Operate automatic enable switch and release.

7. Operate manual start switch.

The system will proceed to take 12 samples and automatically shut down. Repeat step 5 above to flush system.

8. Turn power off.

Sampler Initiation From External Signal

The sampler may be operated in one of two preset modes upon initiation from an external signal.

Up to twelve on-command samples may be taken by setting the single/multiple sample switch to the "single" position and supplying a 1- or 2-second short circuit between the two leads connected to the external jack mounted on the control box. Set up panel as follows:

1. Perform steps 1 through 4 as in automatic mode above.

2. Reset start time counter to zero.

3. Actuate set timer switch, noting time and date for later correlation.

4. Perform steps 4 through 9 as in manual mode above.

5. Operate automatic enable switch and release.

System is now ready to take samples on command from remote source.

If it is desired to collect twelve consecutive samples at preset time intervals, such as during a storm event, the single/multiple switch is set to "multiple" and a 1- to 2-second short circuit signal, as above, is supplied. The first sample will be taken at the end of the first interval as set on T2 with subsequent samples taken at this same interval T2. When using this mode, the clock timer mounted in the control panel will start running when the system is set up and will stop when the first sample is taken. This will provide the time count required to determine when the samples were taken. Set up panel as directly above, steps 1 through 4.

SECTION VII

PRELIMINARY FIELD TESTING

PURPOSE

Subsequent to the fabrication, assembly, and laboratory checkout of the prototype automatic sewer sampling system, it was taken to a nearby site for preliminary field testing. The purpose of this brief series of tests was to demonstrate the ability of the prototype to reliably gather samples in an actual field setting prior to conducting controlled laboratory testing to determine its ability to gather representative samples. Up to this point in time, the prototype had not been used with actual sewage, and it was felt that such use would be beneficial to verify its operational characteristics, especially with regard to freedom from plugging or clogging, etc.

SITE AND INSTALLATION

The site selected for the preliminary field testing was on the Scott Run sewer line which carries sewage from an upper portion of Fairfax County, Virginia under the Potomac River to a main trunk in Maryland leading to the Blue Plains treatment plant in the District of Columbia. The actual sampling site was at the final metering vault located near Virginia State Route 193, just before the line goes under the Potomac. Although under the jurisdiction of the Fairfax County Department of Public Works, the site is actually on Federal park land. The metering vault is entirely below ground, and access to it is controlled by a lock on the vault hatch as well as by a chain link fence with a locked gate that surrounds the vault area.

Thus, the site offered accessability (a truck could be driven to within a few meters of the gate), safety (the site was very well maintained by Fairfax County), protection from possible vandalism, a ready source of fresh water (Scott Run was nearby), and electric power. The sewer itself was a 61 cm (24 in.) diameter concrete line which typically carried flows of around 5.7 to 22.7 million liters per day (1.5 to 6 MGD). There was a slight drop where the sewer entered the metering vault, and a bar screen just upstream of the Parshall flume. The sampling

point was between the entry to the vault and the bar screen (see figure 16) in a fairly turbulent region. The pump housing was placed on the vault floor as shown, which resulted in a lift requirement of slightly less than one meter. The rest of the system was located above ground resulting in a pump discharge head of around 5 meters.

OPERATION

For the first few days of testing, the system was used with no intake other than the open end of each intake tube which was fastened, facing vertically down, to a strut which could be mounted in the flow. This was done intentionally in order to see what plugging or clogging effects might be observed. In earlier attempts to deliberately choke the complete system by artificially introducing a variety of foreign objects, the only difficulty encountered was with a nominal 0.48 cm (3/16 in.) diameter piece of hemp rope approximately 30 cm (12 in.) long. Although this represents a rather unlikely piece of debris to be naturally acquired by the sampler (more than one attempt was required to artificially introduce it in the lab), it was passed by the pump without difficulty. It did prove too large and stiff to enter the diverter line, however, and as a result simply oscillated between the check valve in the fresh water line and the diverter take-off. The system continued to operate, but it is felt that the rope could have acted as a partial filter to some suspended solids resulting in a slight depletion of them in the sample delivered to the container by that particular line.

In the field testing with the open end of the tube as an intake, no difficulties were encountered the first day. On the second day, however, one line picked up a relatively large stone, major dimension approximately 0.63 cm (1/4 in.). The flow at this time was high in heavy suspended solids as witnessed by visual examination of collected samples. The entire bottom of the sample container was covered with settleable solids within less than a minute after collecting the sample. When the stone was ingested it traveled as far as the pump, where it ripped the tubing, causing a leak inside the pump housing. This occurred near the end of the day, and so the entire pump housing was returned to the laboratory for cleaning, inspection, and tube replacement.

On the next day of testing the sampler was installed as before, but monitored closely from within the meter vault.

Figure 16. Sampling Site for Prototype Sampler

No difficulty was encountered. Fairly early in the following day the operator observed another large stone moving up one of the intake lines and into the pump housing. Before the system could be shut down, it entered the pump and stalled the motor, again tearing the tubing. Careful examination revealed no damage to the motor or pump rollers or body other than the ripped tube.

Although it was interesting to note that such large stones (with their high momentum characteristics) could in fact be picked up by the sampler, they are of little use in the typical analysis of wastewater. To avoid a repetition of such incidents, a plastic intake screen was fabricated and used during the remainder of the field testing. This intake screen was a simple cylinder approximately 10 cm (4 in.) in diameter and 30 cm (12 in.) long and containing a large number of 0.48 cm (3/16 in.) diameter holes in its lateral surface to assure free circulation of sewage. Using this screen, no further problem with unwanted debris, stones, etc., was experienced. The intake tubes terminated at different depths within the screen so that effects of varying water levels could be simulated by repositioning the screen in the vertical.

The tests to simulate various water levels were run with one, two, and three intakes above the water level, and the prototype system worked well under all of these conditions. A slight problem exists when an intake is deliberately positioned just at the water-air interface. Since the water surface is not tranquil, the intake is alternately submerged and in the air, with the result that the sample stream in that line is a mixture of air and sewage. The fluidic diverter action is more sluggish or even erratic when the flow stream is high in entrained air. One of two extreme results may occur. If the amount of sewage versus air is sufficiently low, the diverter for that line simply will not switch from drain. This means that the sample collected will have no contribution from that particular intake position, a desirable effect since such a surface skimmed sample may not be as representative as those taken from deeper in the flow. A similar effect may occur when a submerged intake line is partially blocked resulting in a sample stream that is free of entrained air but moving at a low flow rate. In laboratory tests this phenomenon was observed at flow rates around 3.8 ℓpm (1 gpm) or less. Again this is seen as beneficial, since such lower velocity flows may not be as representative in the heavier suspended solids.

The second result occurs when there is relatively more sewage than air but still a considerable quantity of bubbles in the line. Under such conditions the diverter may switch, but its action is very sluggish. This means that when the sample container is filled to the desired level and the signal is given to switch the diverters back to drain, the diverter in the line with entrained air may not switch immediately, and that line will continue to empty into the sample container. The result is that the sample container will be overfilled or, in some cases, even overflow slightly. In cases where such overflows occurred, they did not appear to be large enough to affect sample representativeness due to the resulting decanting action. They did require an additional clean-up step at the end of a complete event cycle, namely the wiping of the table under the sample container that had overflowed.

One other minor difficulty was encountered during the preliminary field testing of the prototype automatic sampling system. Since the fluidic diverters are mounted on the rotating distribution arm, the single tube that returns the flow to waste must undergo a rotation of approximately 350° over the course of a complete event cycle. During one installation test series at Scott Run the system overflowed, an event that was subsequently traced to a kink that had developed in this drain line and restricted the flow returning to waste. Consideration was given to the installation of a swivel fitting, but it was found that the problem did not develop if careful attention was paid to the position and routing of the drain tube at installation.

In summary, the prototype automatic sewer sampling system appeared to work well under all conditions encountered during the preliminary field testing when the maximum admissable particle size was reduced to 0.48 cm (3/16 in.) with an intake screen. There were no instances of plugging or clogging, and all automatic aspects of the control system functioned satisfactorily. Since the quality characteristics of the flow were unknown, none of the collected samples was subjected to laboratory analysis. Visual inspection revealed a surprising quantity of light, floatable solids on several occasions as well as the heavy, settleable solids mentioned earlier. As a result of the overall satisfactory operation of the prototype system, it was decided to proceed with the controlled laboratory testing in order to examine the ability of the system to extract a representative sample from flows of known characteristics.

SECTION VIII

CONTROLLED LABORATORY TESTING

OBJECTIVES

Although considerable data have been collected that purport to reflect the ability of a particular piece of automatic sampling equipment to gather a representative sample from a wastewater stream, in no instance have the actual quality characteristics of the stream been known. Similarly, there have been a few side-by-side comparative tests run using automatic samplers of different designs and manufacturers, always with differences in results, but since the wastewater streams used were ones of opportunity having unknown characteristics, only relative comparisons were possible. For example, Harris and Keffer (11) report differences of over 200 percent among samplers of different designs when applied simultaneously to the same wastewater stream. In view of this state of affairs, it had been decided to perform a series of tests using a synthetic wastewater stream which could be controlled as to such parameters as flow depth and velocity and suspended solids characteristics including specific gravity, size, and concentration.

There were three primary objectives to the controlled laboratory testing activities. First, the extreme difficulty in creating a tightly controlled (e.g., ±5%) synthetic waste stream was well recognized. Both continuous-flow closed-loop tests and open-loop, batch-fed tests had been performed in the past, primarily in relation to sediment transport and sampling studies, and considerable data scatter was observed. Therefore, one objective was to determine the capability to produce stable, controlled flows containing synthetic suspended solids that simulated those found in storm and combined sewers.

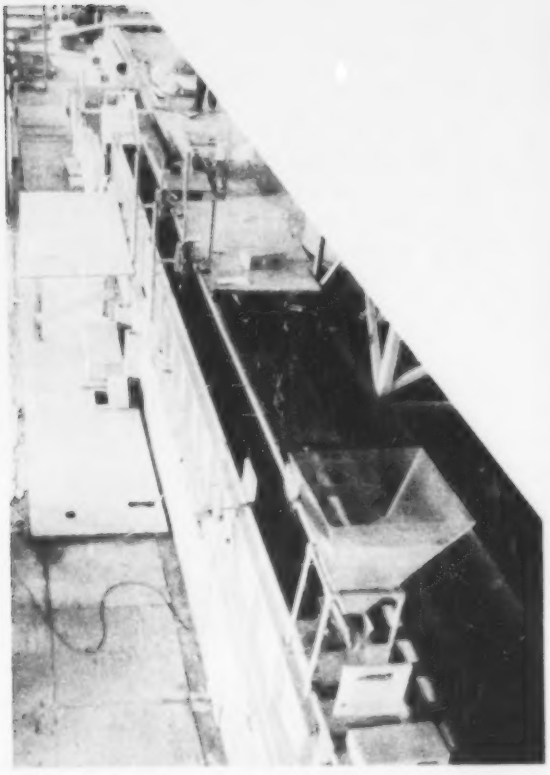
The second objective arose from the design and fabrication of the prototype automatic sewer sampling system. It was desired to quantify and evaluate the capability of this device to gather samples representative of the wastewater stream in question, especially as regards suspended solids, under various flow conditions. Again the use of a controlled, synthetic flow seemed to be the only means of obtaining absolute rather than relative data.

Finally, it was desired to comparatively evaluate a number of the more popular commercially available automatic sampler designs in a side-by-side fashion with the prototype sampler. This would indicate whether or not, in fact, any actual improvements in the ability to gather a representative sample had been achieved with the prototype design. A second benefit, of course, would be the opportunity to compare these commercially available designs with each other to see which ones were best suited for gathering samples that are representative as to suspended solids, and to do this against a known base.

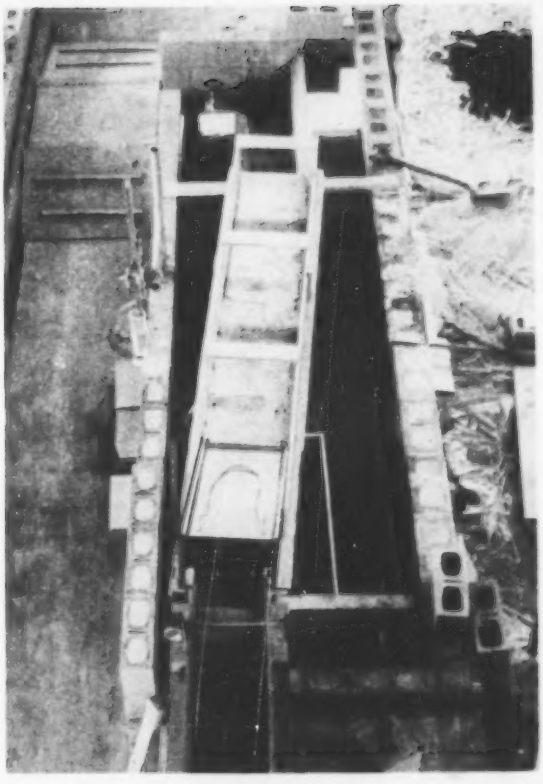
FACILITY

A number of requirements for a facility to be used for the sampler controlled laboratory testing were identified. These included a test flume with a semi-circular invert, the ability to create stable flows over the velocity range of 0.3 to 2.4 m/s (1 to 8 fps) while maintaining a constant depth in the test section, an accurate means of determining flume discharge (i.e., flow velocity), a method for constantly adding synthetic suspended solids to the flow so as to create and maintain a known solids concentration in the flume, the ability to provide suitable synthetic solids representative of those encountered in storm and combined sewer flows, and the ability to provide laboratory analysis of samples taken during the testing program.

The LaSalle Hydraulic Laboratory Ltd. (LHL) facility was used for the controlled laboratory testing. Briefly, it consisted of a water supply taken from a fixed pumping station in the laboratory, the flow channel or flume itself, a settling basin with a calibrated overflow weir, and an exit to a return channel to the pump. The flow channel was 12.2m (40 ft) long with a cross-section 0.3m (1 ft) wide by 0.6m (2 ft) deep, including a semicircular invert (see figures 17 and 18). A test section was provided 3.7m (12 ft) from the downstream end where a 2.54 cm (1 in.) recess in the wall was provided to allow routing the 1.6 cm (5/8 in.) O.D. tubes from the intakes of the prototype sampler to its pump box. This was done, in view of the channel width, to minimize any effects of these lines on the flow stream itself. Point gages upstream from the test section could measure the water level to ensure that depth control was maintained.

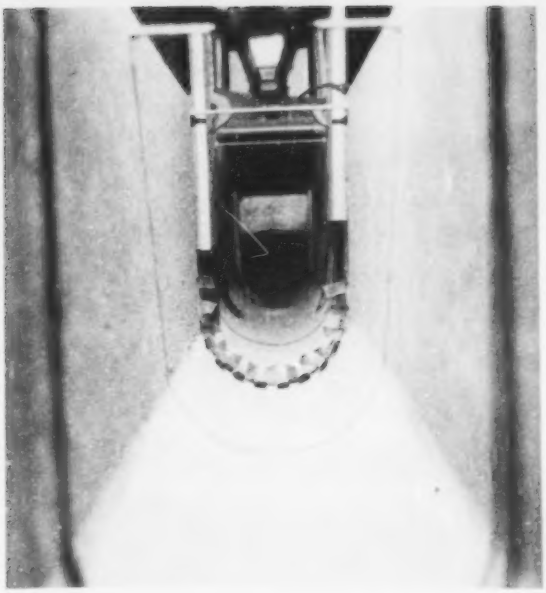


General View of
Test Channel



Channel Outlet
Showing Diversion
Chute and Catch Basin

Figure 17. General Test Facility Arrangement



View Inside Chute
Showing Cross Section
and Turbulence
Enhancer in Place

Solids Materials
Injection Vibrator

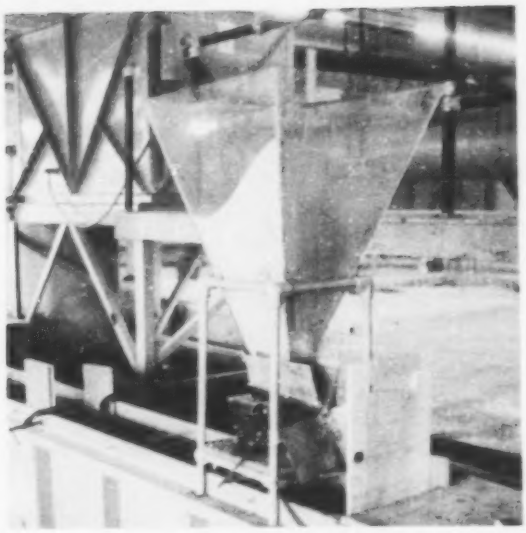


Figure 18. Test Facility Details

The normal water supply was taken directly from the pump. The flume and overflow weir were calibrated by a temporary supply which took its flow directly from one of the calibrated V-notch weir towers in the laboratory. The solids injection system consisted of a dry solids vibratory feeder with a plexiglass hopper fixed over it. The rate of vibration (and hence solids injection) could be controlled by a rheostat. A turbulence enhancer made of sheet metal with alternating twisted blades was used for many of the runs in an attempt to reduce vertical concentration gradients.

A wide range of suspended solids were available for creating the synthetic flows. They were:

a. Silica sand, specific gravity 2.65
   fine - 120 mesh $\geq$ d $\geq$ 140 mesh (.105-.125 mm)
   medium - 30 mesh $\geq$ d $\geq$ 35 mesh (.500-.595 mm)
   coarse - 10 mesh $\geq$ d $\geq$ 12 mesh (1.68-2.00 mm)

b. Pumice, specific gravity 1.35
   A single broad grain size distribution used in earlier storm and combined sewer flow synthesization was tested;
   6 mesh $\geq$ d $\geq$ about 100 mesh (.149-3.36 mm)

c. Gilsonite, specific gravity 1.06
   fine - 12 mesh $\geq$ d $\geq$ 30 mesh (.595-1.68 mm)
   medium - 10 mesh $\geq$ d $\geq$ 12 mesh (1.68-2.00 mm)
   coarse - 6 mesh $\geq$ d $\geq$ 8 mesh (2.38-3.36 mm)

d. Alathon, specific gravity 0.99
   Uniform size of 3.0 mm

e. Polythene, specific gravity 0.92
   Uniform size of 4.0 mm

These synthetic suspended solids may be considered as representing, either directly or through hydrodynamic simulation, a wide range of suspended solids typically encountered in storm and combined sewer flows. For example, the sand is typical of many mineral and soil particles, sediments washed from construction projects, etc.; the pumice may be considered representative of a host of heavier organics, rubber and asphalt particles, etc.; the gilsonite is representative of the lighter organic suspended solids, many plastics, etc.; and the alathon and polythene represent the range of many floatables, organic as well as inorganic. For the majority of the testing program, fine sand and medium gilsonite were used, for reasons that will be discussed subsequently.

INITIAL PROTOTYPE SAMPLER TEST RESULTS

The initial phase of the controlled laboratory testing program involved using the prototype automatic sewer sampler over a wide range of test parameters (flow velocity, solids type and size, and concentration). The positions of the four sampling intakes used for the large majority of the testing are indicated in figure 19. As can be noted, two were located near mid-depth while the other two were positioned near the water surface and near the invert respectively. This arrangement is essentially similar to the preferred three-point method of sampling discussed in (12). The notion is that the mean of the upper half of the concentration will be approximated by the average of the surface and mid-depth values, and the mean of the lower half by the average of the mid-depth and bottom. Thus, as noted in (12), "a composite sample made up of two samples from mid-depth and one each from the surface and bottom, all of equal volume, approximately represents both concentration and size distribution."

In addition to the prototype sampler, a so-called "reference" sampler was used in part of this initial testing phase. The reference sampler consisted of a "standard" sedimentation probe (provided through the courtesy of the Federal Inter-Agency Sedimentation Project Office at St. Anthony Falls) connected to a peristaltic pump with a variable speed drive arrangement. This reference sampler had been calibrated so that any desired sample intake velocity could be set in order to allow isokinetic sampling to be achieved. The intake probe could be positioned at any desired point in the cross-section of the flow with its inlet pointed directly upstream into the flow. The reference sampler was used primarily to investigate vertical and horizontal concentration profiles.

As mentioned earlier, a number of suspended solid types were tested only briefly. The two floatables, alathon and polythene, were essentially confined to the surface layer of the flow, and the prototype sampler, with its uppermost intake around 3.4 cm (1.35 in.) below the surface, was unable to gather a representative sample. The quantities of these solids in the samples were so small that they could virtually be counted by hand. The prototype sampler was not designed for use with floatables, and these brief tests serve to point out the need for specially designed intakes if representative samples of floatables are to be gathered. Determining mass discharges (say Kg per day) will be complicated

Note: Intake height above invert as a percent of total water depth as indicated in parenthesis.

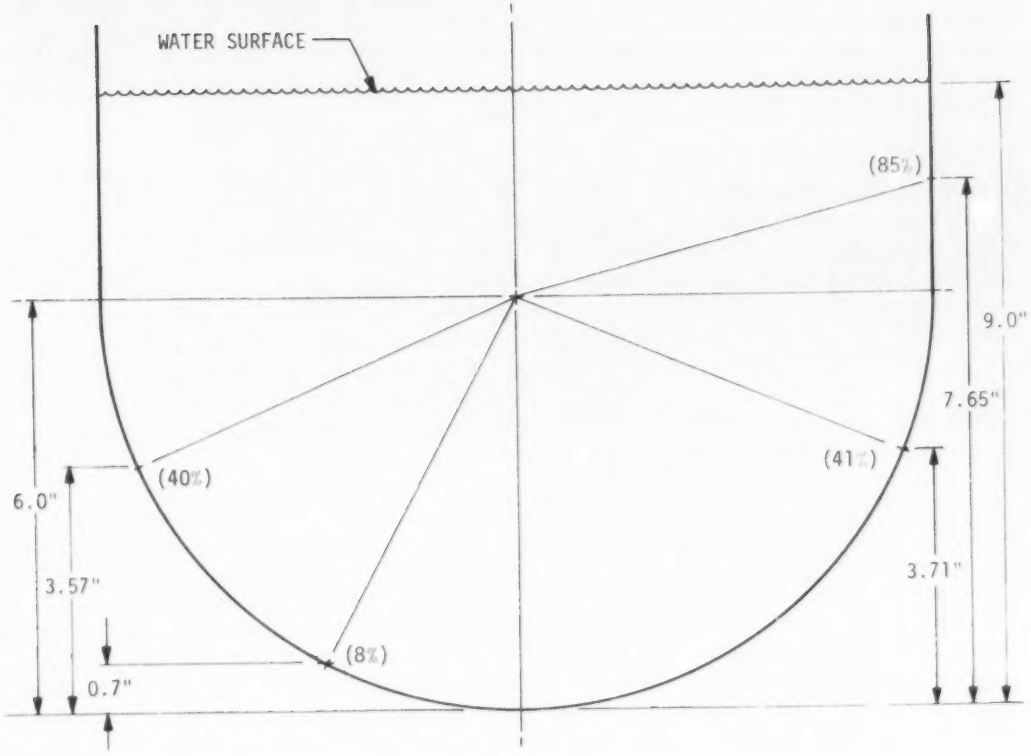


Figure 19. Intake Location of Prototype Sampler

by sharp vertical concentration gradients and the fact that transport rates of surface-carried solids may well differ from those of the main stream due to vertical velocity gradients.

The coarse sand was tested only briefly also. Even at flow velocities of 2.4 m/s (8 fps), virtually all of the material was transported as bed load. Very little could be gathered with the reference probe when it was positioned over 1.3 cm (1/2 in.) above the bed load. Consequently, samples taken with the prototype sampler were not at all representative. As long as the bed load depth was below the lowest intake, no appreciable quantity of these solids would be picked up. Conversely, when the bed load level reached the lowest intake, a sand slurry was collected, and the combined sample would reflect concentrations an order of magnitude or more greater than those of the flume.

A similar effect, although less pronounced, was observed when using the medium sand. A relative concentration profile is presented in figure 20. The mean concentration is the average of four samples taken with the prototype sampler. Their variation with time is also indicated in figure 20. The relative concentration profile is the plot of points representing the concentration of a sample taken at a particular depth with the reference sampler divided by the mean concentration. As can be noted, the concentration gradient is very sharp, the average occurring only some 6.4 cm (2.5 in.) above the invert.

The variation of sand concentration with time is better illustrated by figure 21. Here the results of samples taken by the prototype sampler at 60 second intervals are presented for both fine and medium sand with a flow velocity of 1.2 m/s (4 fps) in the flume. The standard deviation for the medium sand is 202, almost twice the 110 for the fine sand. The wider range of the results using medium sand is attributed to the fact that at this velocity, a good portion of it moves as bed load, and the more random dune movement near the vicinity of the lowest intake was at least partially responsible for the larger variation in results.

There was also considerable bed load build up with fine sand at 1.2 m/s (4 fps). This is best illustrated by figure 22 which presents the results of a brief look at bed load effects. Here a fairly heavy feed rate (a little over 1200 mg/ℓ equivalent concentration) was established, and the

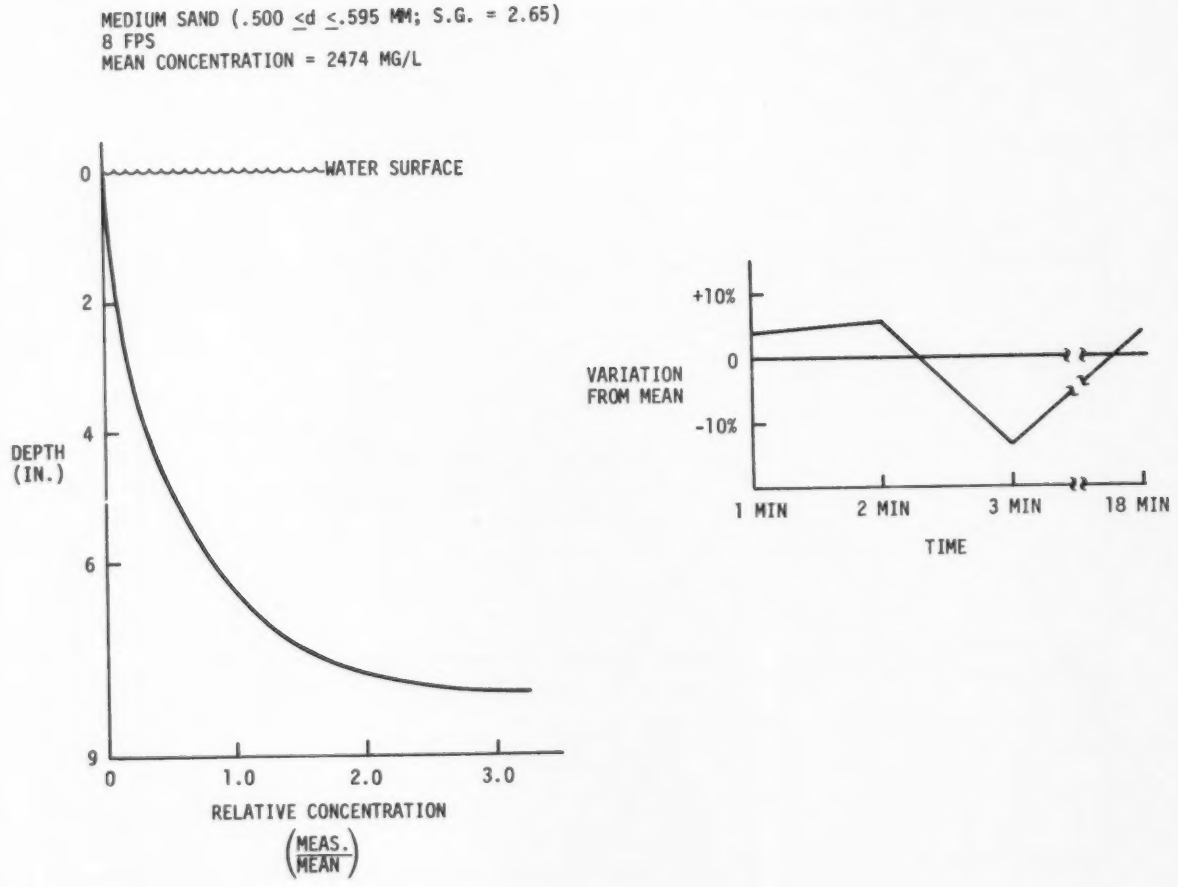


Figure 20. Relative Concentration Profile

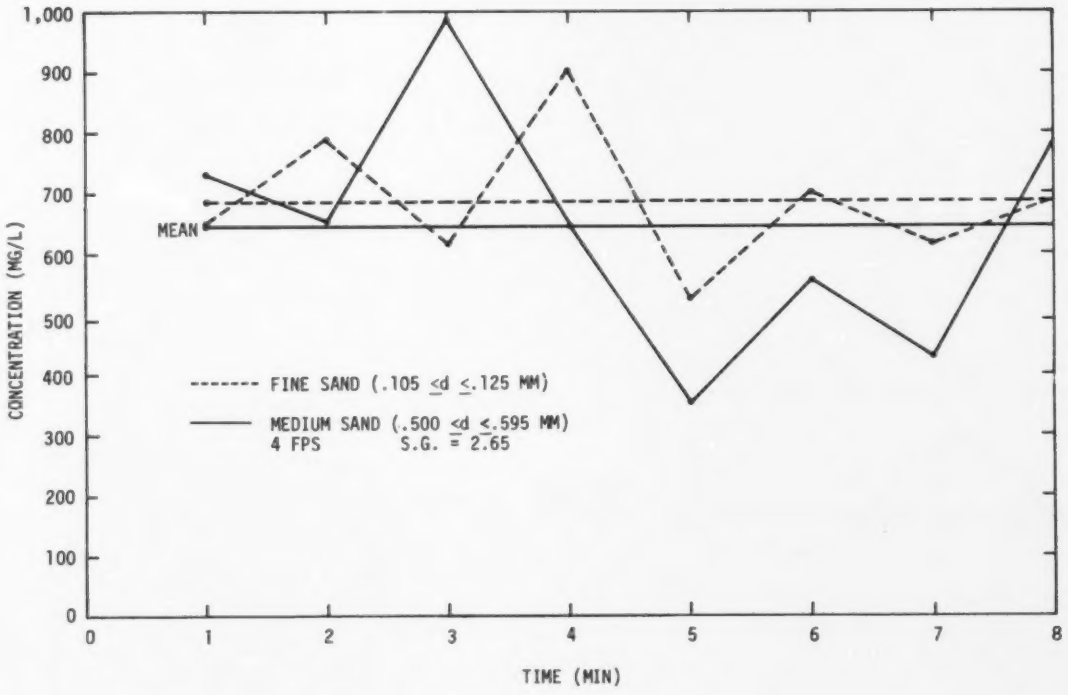


Figure 21. Variation of Sand Concentration with Time

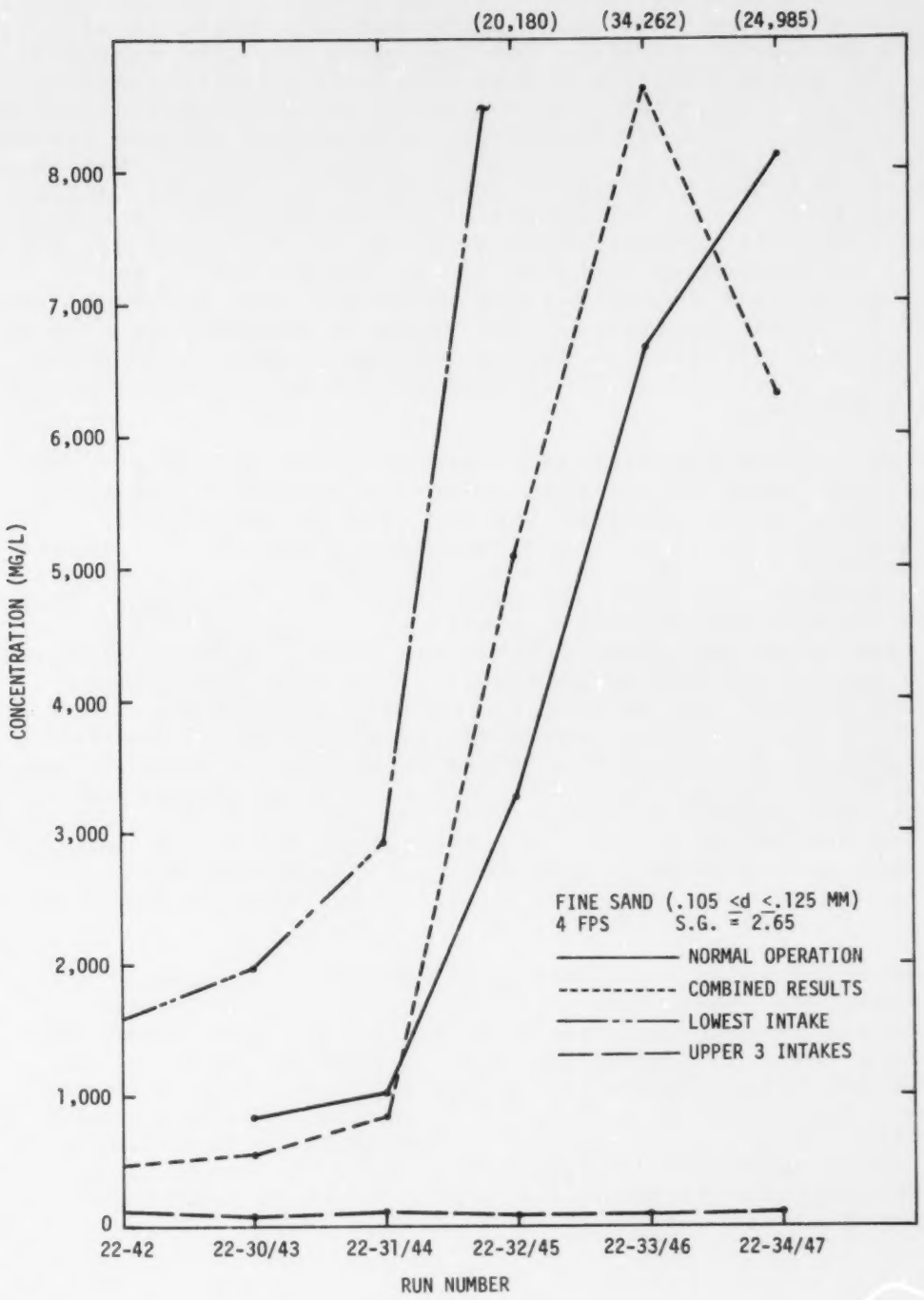


Figure 22. Bed Load Effects

prototype sampler was used in normal operation to take samples at 30 second intervals as the bed load began to approach the lowest intake. The procedure was then repeated with the sample from the lowest intake being directed into one container and that from the upper three intakes directed into another. They were analyzed separately, and the results are shown in figure 22. It can be noted that the upper three intakes contribute virtually nothing to the overall sample concentration. The combined results are obtained by adding three times the concentration gathered by the upper intakes to the concentration gathered by the lowest intake and dividing by four to reflect the weighting that would be provided by normal operation. The curve so obtained is seen to be qualitatively similar to the earlier results from normal operation and reflects the effect of bed load inundating the lowest intake.

Limited testing was also performed with the coarse and fine gilsonite. Much of the fine gilsonite tended to remain in the surface layer (surface tension effects outweighed gravitational ones) and, consequently, could not be sampled effectively. It also tended not to settle out in the settling chamber, and material would blow over the weir. Therefore, further use of this material was abandoned. There did not seem to be any great differences in the results obtained using coarse and medium gilsonite so, due to the greater availability of the latter, it was used extensively. The variation of gilsonite concentration with time is depicted in figure 23 for flume velocities of 0.6 and 1.2 m/s (2 and 4 fps). The flume concentration was normally determined by taking five samples directly from the shaker feed at the beginning and end of a run. The average of these ten readings was used as the flume concentration. The shaded areas in figure 23 indicate the range within which these calibration samples fell for each run.

As mentioned earlier, a turbulence enhancer was installed to attempt to reduce the vertical concentration gradients. It did not produce as great a change as had been hoped for as can be seen in figure 24, which indicates relative concentration versus depth for medium gilsonite both with and without the turbulence enhancer installed. There was also no great effect on the relative concentration variation with time as is indicated by figure 25. None the less, it was decided that the turbulence enhancer would be used for the remainder of the tests.

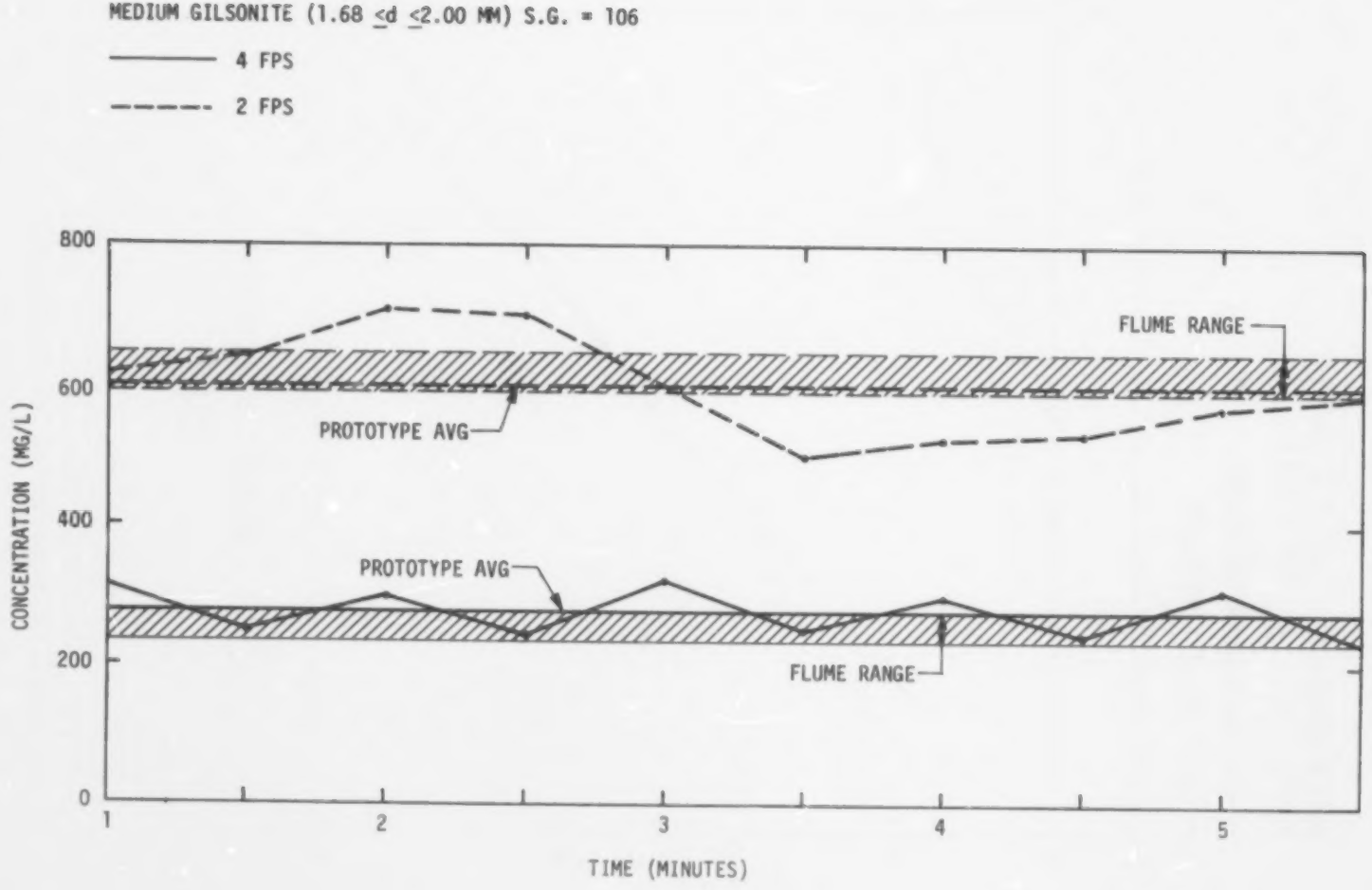


Figure 23. Variation of Gilsonite Concentration with Time

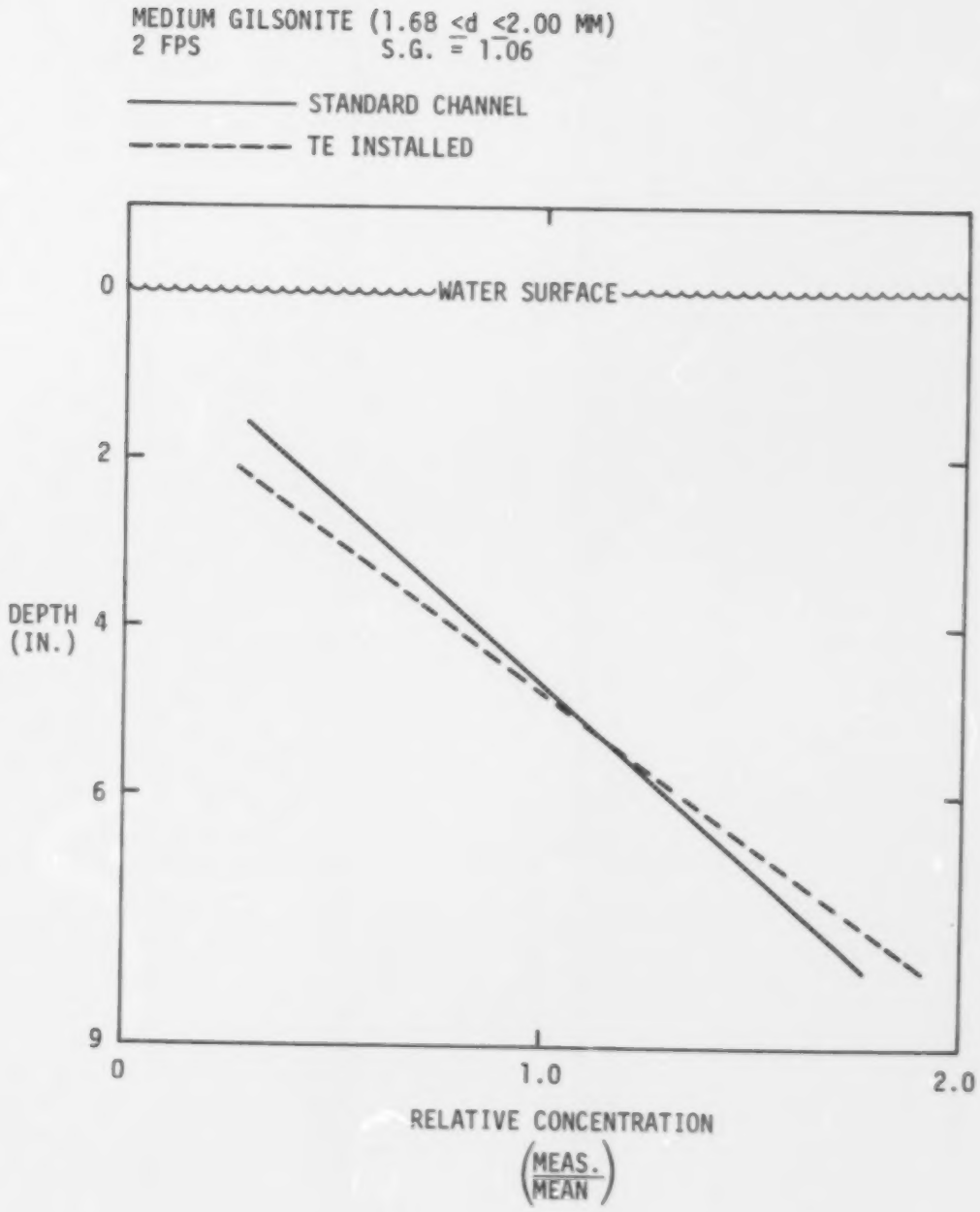


Figure 24. Effect of Turbulence Enhancer on Relative Concentration Gradient

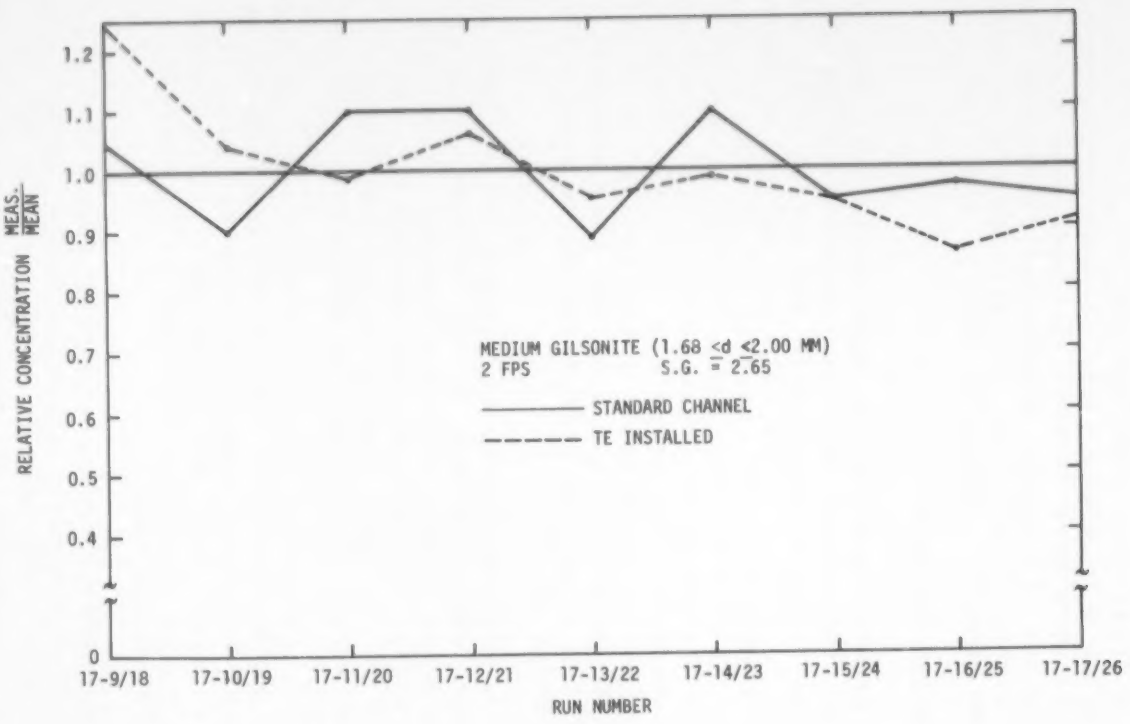


Figure 25. Effect of Turbulence Enhancer on Variations with Time

Finally, a relatively small amount of testing was conducted using ungraded pumice. Typical vertical concentration profiles taken with the reference sampler for two similar flume concentrations (near 600 mg/ℓ) are shown in figure 26. The variation of samples taken with the prototype sampler at 30 second intervals from the actual flume concentration is also depicted in figure 26. The average of each 12-sample set is indicated as a straight line for each concentration. The main thing to note here is that the prototype sampler tended to understate the pumice concentration at this low velocity. For higher velocities, the average concentration from the sampler tended to approach that of the flume.

COMPARATIVE TESTING RESULTS

In view of the growing quantity of data suggesting that the use of automatic samplers of different designs may result in widely varying results, see Harris and Keffer (11), it had been decided to devote a few days of controlled laboratory testing to side-by-side comparisons of some of the more popular models of commercially available equipment. This would allow direct comparisons to be made of performance in a known stream. The prototype automatic sampling system was also used to ascertain if any actual improvements over commercially available equipment had been achieved as regards the ability to gather a representative sample with respect to suspended solids.

There is a wide variety of gathering methods and different design implementations available in the automatic sampler equipment marketplace today. For the limited comparative testing phase of this project, it was decided to use examples of some of the more popular gathering methods. It must be emphasized that the intention was not to study a particular design in detail but, rather, to attempt to ascertain how successfully the selected models would perform when sampling suspended solids. The gathering methods employed by the four selected commercial samplers were (1) slow speed peristaltic pump, 0.15 ℓpm (0.04 gpm); (2) moderate speed peristaltic pump, 1.5 ℓpm (0.4 gpm); (3) pneumatic ejection; and (4) vacuum pump.

Each of the commercial units was equipped with a different type of intake. The pneumatic ejection device comes equipped with a special intake that must be used in order for the unit to operate. The two peristaltic pump devices were equipped with weighted cylindrical screens for intakes, and the vacuum pump unit simply had a brass weight on the end of the intake

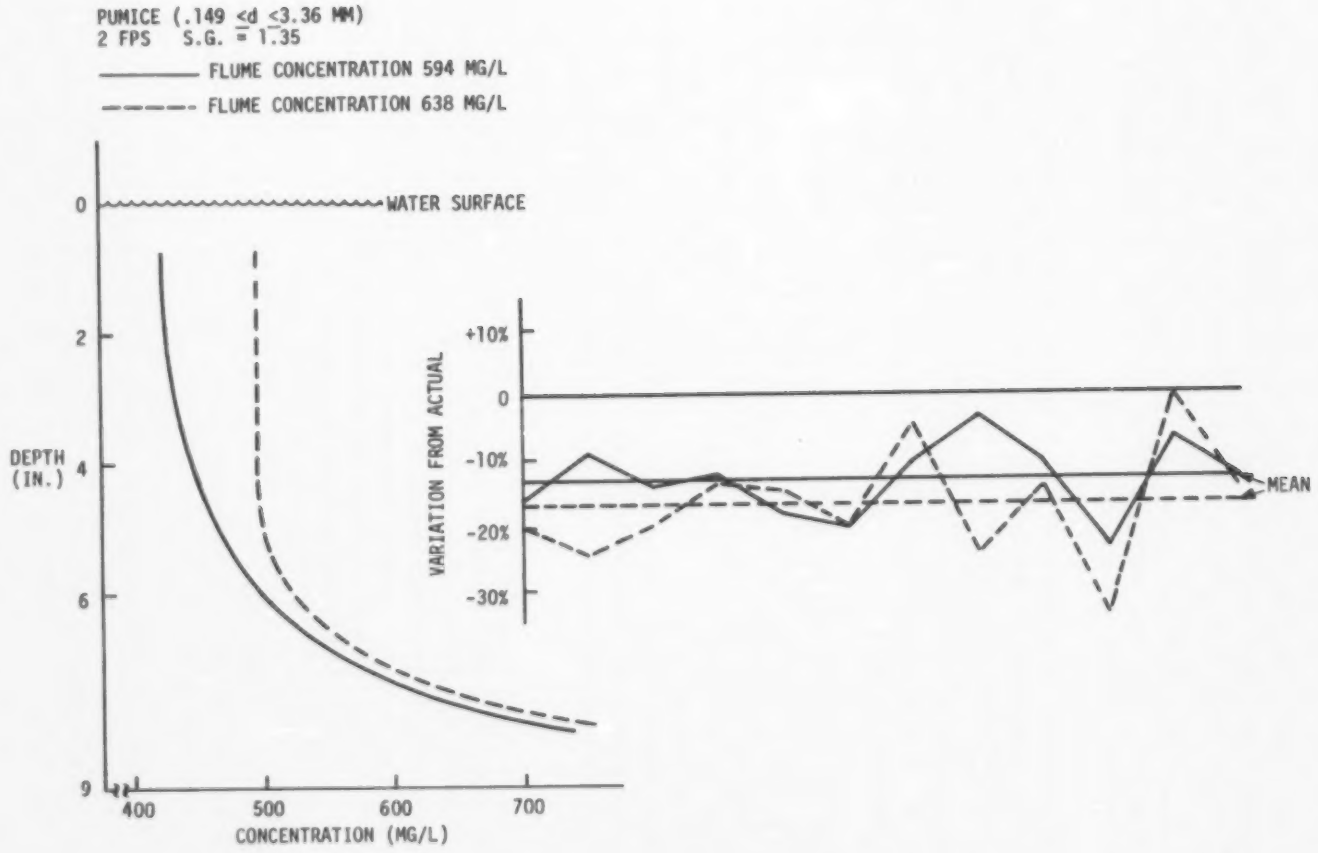


Figure 26. Pumice Concentration Profiles

hose. These latter three intakes could be modified by a prospective user to meet his particular needs, but the pneumatic ejection unit's intake must be used as supplied.

In order to avoid any suggestion of equipment misuse, each of the manufacturers invited to participate in the testing were asked to provide their own personnel to operate and maintain their respective equipment. Similarly, each manufacturer was allowed to install his intake in the test channel in whatever way he felt would be most advantageous to his particular piece of equipment.

Space limitations precluded the simultaneous installation of all four commercial samplers at the same time. Therefore, two were tested during the week of July 22 and the other two were tested during the week of July 29. The same test parameters were used for both pairs of commercial samplers, and the prototype sampler was used throughout both series of tests.

Based upon the results of the earlier tests that had been run using the prototype sampler, it was decided to concentrate on fine sand and medium gilsonite for the comparative testing. Average flow velocities of 0.6 and 1.2 m/s (2 and 4 fps) were used with the gilsonite and 1.2 and 2.4 m/s (4 and 8 fps) with the sand. Two concentrations, nominally 300 and 600 mg/ℓ, were used for each velocity/solids combination. Five samples were taken with each device for each combination of parameters. The raw data are plotted in the Appendix.

One measure of performance of an automatic sampler is its so called "sampling efficiency" or, as it will be termed here, sampling representativeness. This number, which is usually expressed on a percentage basis, is the concentration of the sample gathered by the unit divided by the actual concentration of the flow. Thus, exact one-to-one representation results in a sampling representativeness of 100 percent. Sampling representativeness numbers of less than 100 percent indicate that concentrations (and hence mass discharges, total pollutant loadings, etc.) will be understated, while numbers greater than 100 percent mean that concentrations are being overstated.

Obviously a device that consistently performs with a sampling representativeness of 100 percent is ideal. However, a device that consistently performs with a sampling representativeness of, say, 80 percent can also be very useful. The

important thing is its repeatability and its consistency of representativeness, which can be viewed as a sort of calibration factor.

Summary results of the comparative testing phase of the program are presented in terms of sampling representativeness averages in Table 2. The unaveraged sampling representativeness data are plotted in figure 27. Since it was not the intention of this project to endorse or critize any particular piece of sampling equipment, the commercial units are simply designated as Models A, B, C, and D. A few interpretative comments are in order.

The overall performance of the prototype sampler appears to be relatively good, especially for the gilsonite flows. For the fine sand its performance was more erratic. At 1.2 m/s (4 fps), much of the solids were flowing along the invert as bed load and were beneath the level of the lowest intake port, accounting for the general understatement of concentration at this velocity. When the flow velocity was doubled to 2.4 m/s (8 fps), the quantity of sand transported as bed load was reduced, and higher concentrations were seen by the lowest intake port. This explains the average 48 percent overstatement of concentration experienced by the prototype sampler under this set of conditions.

The Model A commercial sampler was a forced flow, pneumatic ejection-type using pressurized gas to force the sample from the intake chamber in the flow up to the sample container housed within the instrument case. The sample intake used had a nominal 250 mℓ capacity and was gravity filled, after discharge of the previous sample, through eight ports evenly spaced around its periphery. As is typical of this type sample, it must be used with its own specially designed intake. A 0.64 cm (1/4 in.) ID line was used to transport the sample from the intake to the container. The performance of this unit for gilsonite flows was relatively good, being more erratic than the prototype, but better in this respect than the other three commercial units. The unit was unable to gather any appreciable quantity of the fine sand, however, apparently because of its intake design.

The Model B commercial sampler was a suction lift unit that utilized a moderate speed peristaltic pump and 0.64 cm (1/4 in. ID) sample transport tubing. The intake provided was a weighted plastic cylindrical strainer with four rows of five 0.32 cm (1/8 in.) holes evenly spaced around its periphery. This unit suffered from a kinked hose in the intake line which probably occurred early in the morning of

TABLE 2. AVERAGE SAMPLING REPRESENTATIVENESS (%)

Solids Type Flow Velocity (fps) Nominal Concentrations (mg/ℓ)	MG 2 300	MG 2 600	MG 4 300	MG 4 600	FS 4 300	FS 4 600	FS 8 300	FS 8 600
Prototype	110	116	104	99	40	37	138	157
Model A	76	74	100	61	2	0	9	12
Model B	74*	93	14	1	5	3	26	33
Model C	159	199	90	68	74	343*	60	16
Model D	440	411	298	156	36	30*	12	3

NOTES:

- Sampling representativeness is analyzed sample concentration divided by average actual flume concentration times 100.
- Prototype data based upon 10 point average; all others are 5 point averages except * where one data point was disregarded leaving a 4 point average.
- MG is medium gilsonite (S.G. = 1.06, $1.68 \leq d \leq 2.00$ mm); FS is fine sand (S.G. = 2.65, $0.105 \leq d \leq 0.125$ mm).
- Multiply feet per second by 0.3 to obtain meters per second.

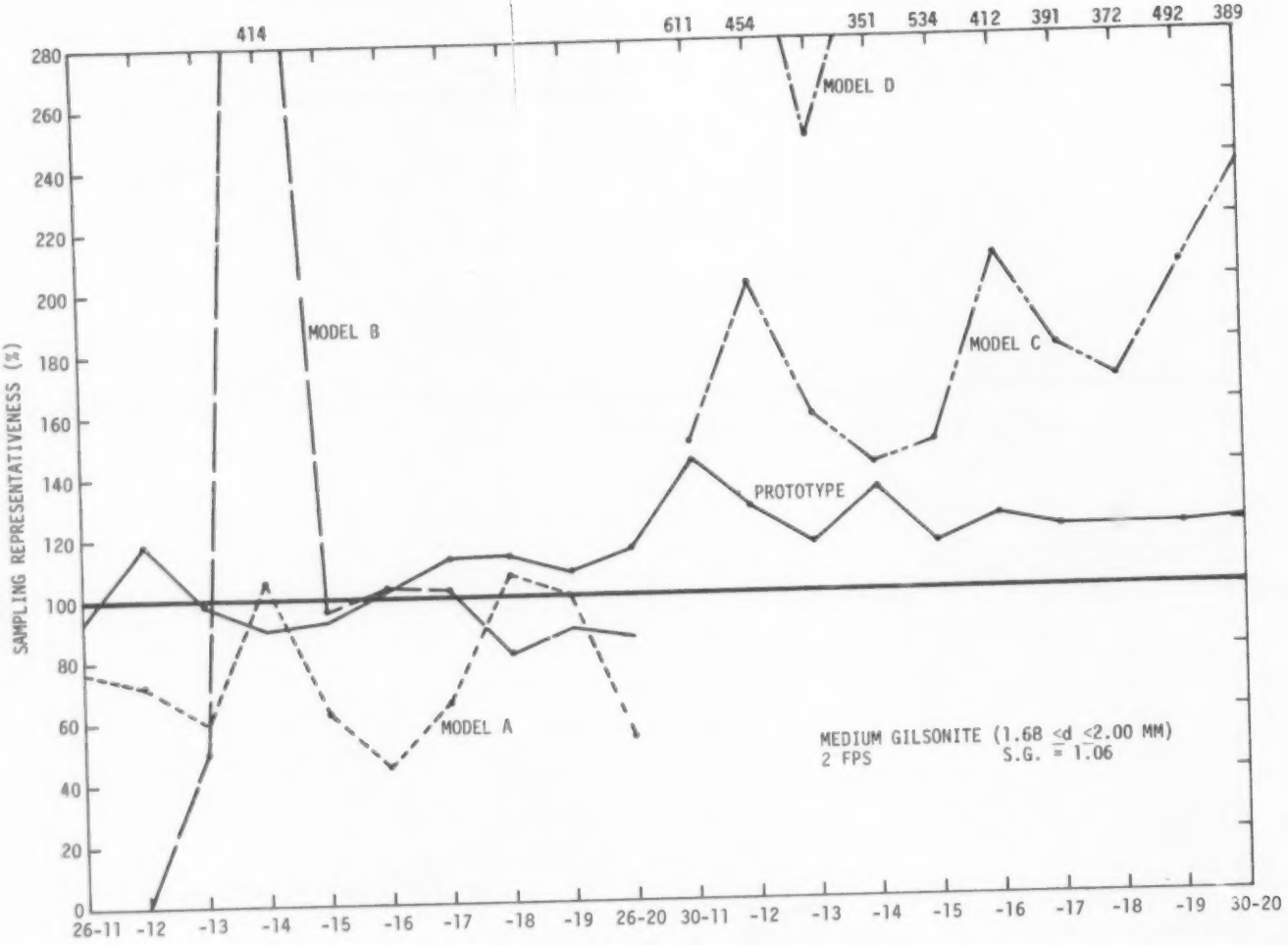


Figure 27. Sampling Representativeness (Sheet 1 of 4)

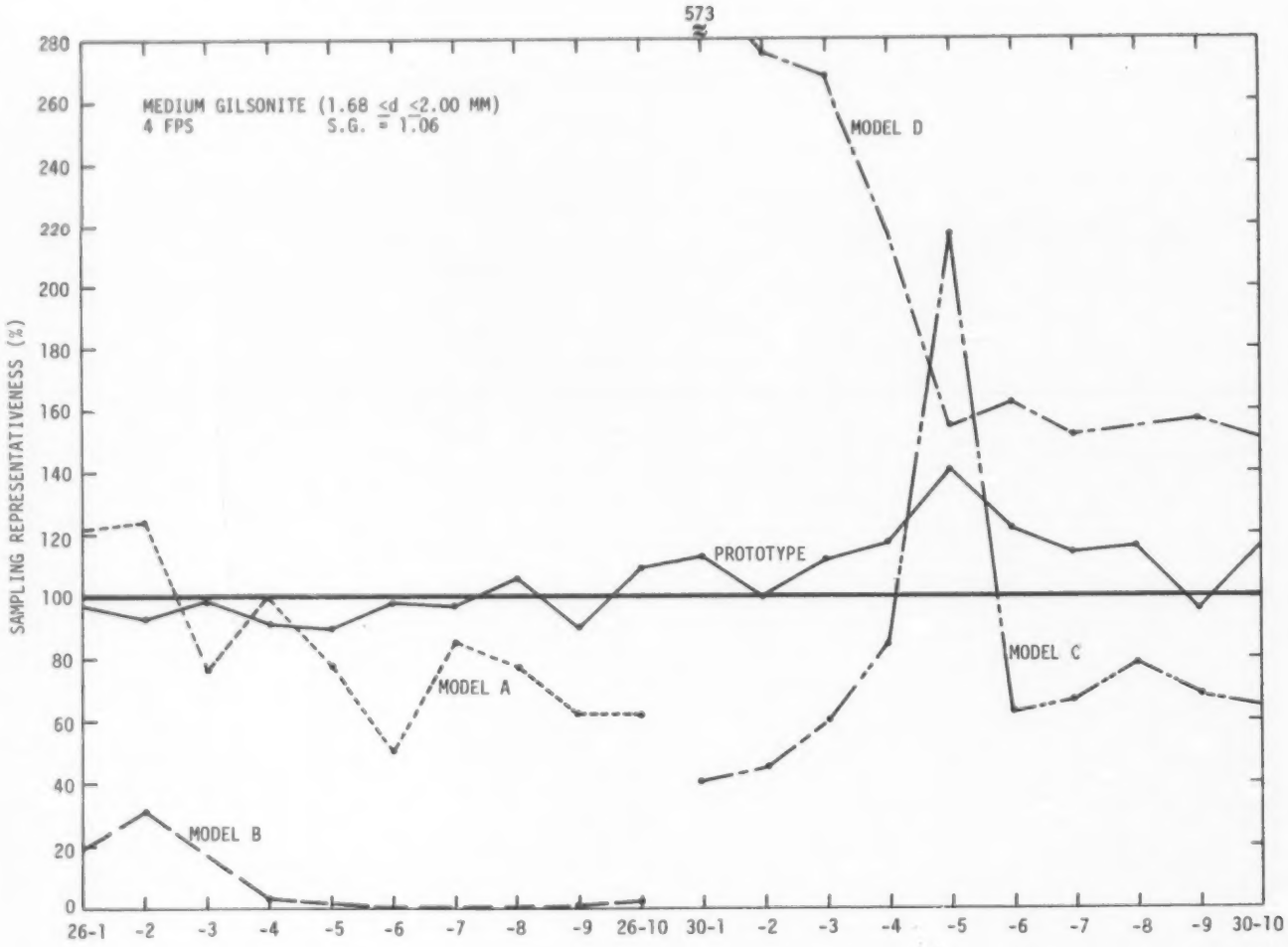


Figure 27. Sampling Representativeness (Sheet 2 of 4)

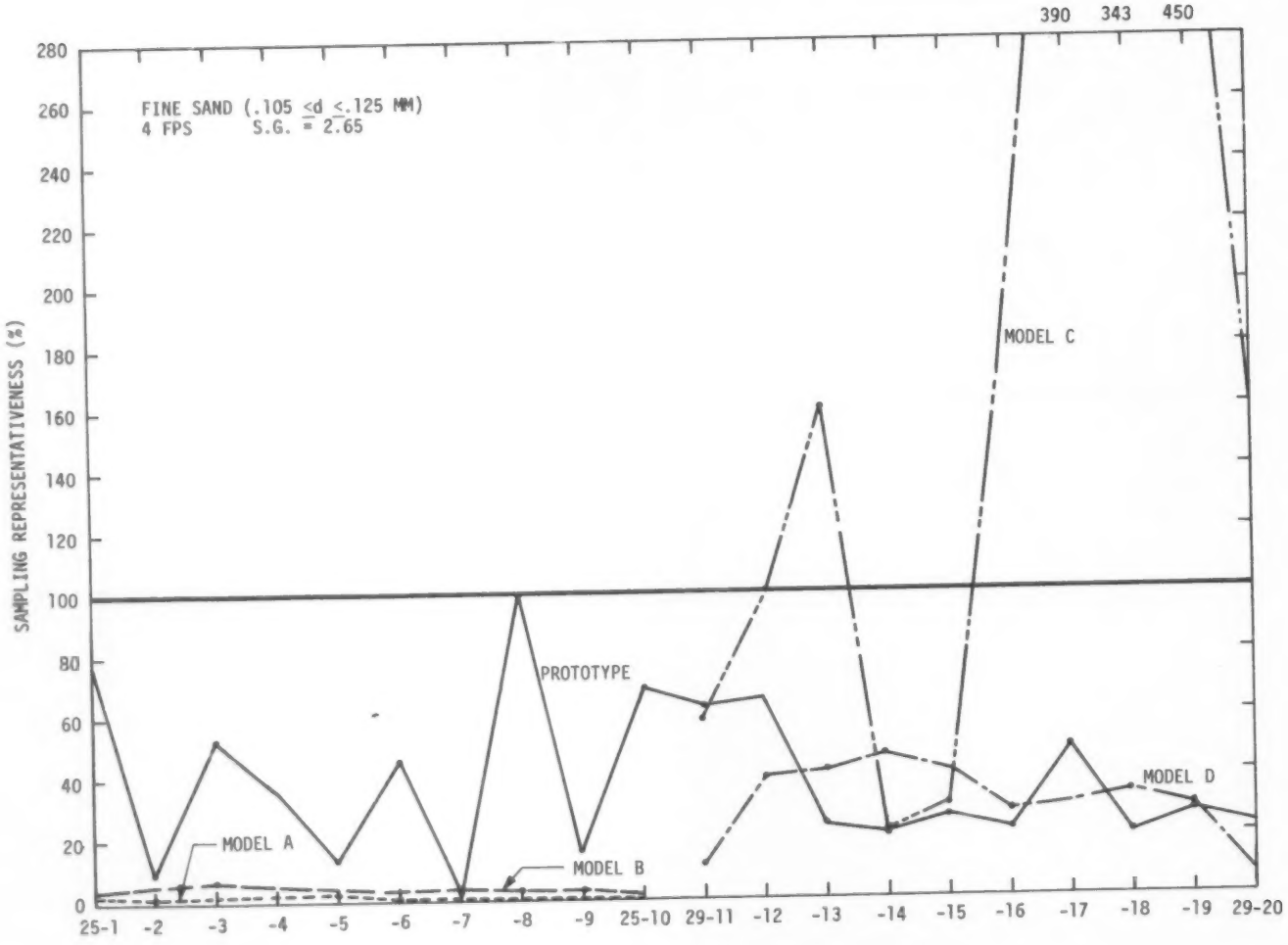


Figure 27. Sampling Representativeness (Sheet 3 of 4)

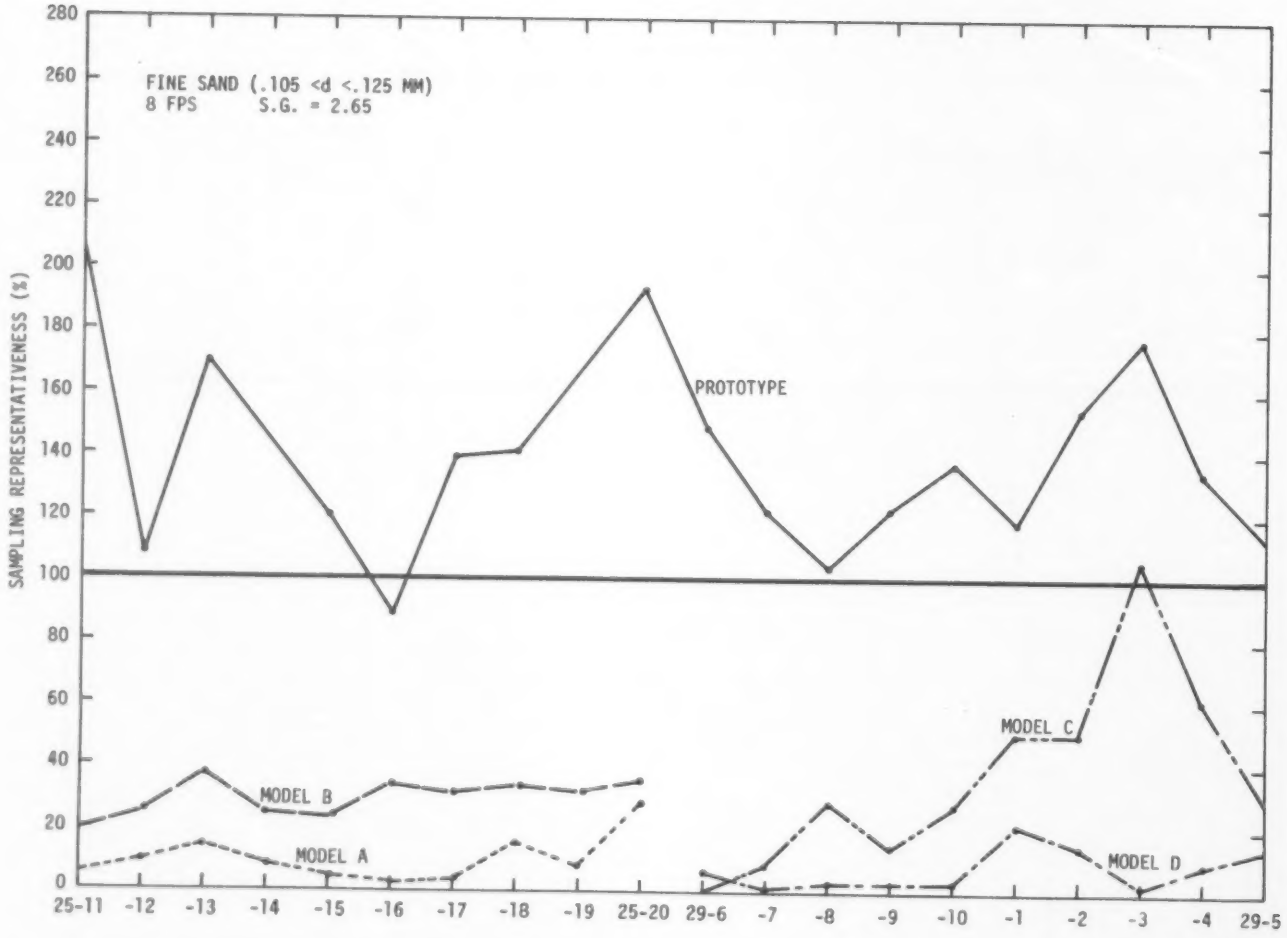


Figure 27. Sampling Representativeness (Sheet 4 of 4)

July 26 (beginning with run 26-1) and was not detected until after run 26-12. This accounts for its poor performance during this period. Otherwise, its performance with gilsonite was fairly good. There was a problem with intake orientation (a result of its design) during runs 25-1 through 25-10 which accounts for the units' poor performance with fine sand at 1.2 m/s (4 fps). Correcting this situation by repositioning the intake resulted in some improvement in operation with fine sand at 2.4 m/s (8 fps), but the unit was still unable to gather appreciable quantities of this material.

The Model C commercial sampler was a suction lift type device that used a slow speed peristaltic pump with 0.64 cm (1/4 in.) ID tubing. It was used both with and without its plastic intake screen, which was a weighted cylinder whose lateral surface was formed by rolling up a sheet of plastic perforated with a large number of 0.32 (1/8 in.) holes. The vertical position of the end of the suction tube within the intake screen was adjustable. The performance of this unit tended to be erratic, and no general explanation for its behavior can be made at the present time.

The Model D commercial sampler was also a suction lift type device that used a vacuum pump to evacuate a metering chamber into which the sample was drawn prior to expulsion into the sample container. Its intake was simply the unscreened end of the plastic suction tube with a weight attached. The unit's performance would appear related to the intake design. As flow velocities increase, the elevation of the intake above the invert increases and, therefore, the intake can be located in a region of relatively lower concentration. This, combined with the difficulty of gathering the higher density sand particles, would appear to explain this piece of equipments' gross overstating of flow concentrations with gilsonite and understating flow concentrations with sand.

DISCUSSION

The results of the controlled laboratory testing phase of the project are encouraging, except for the ability to representatively sample some flows containing heavy suspended solids. Fairly good results were obtained with the prototype sampler when most of the particles were in suspension in the flow (even for those falling somewhat outside the range of validity of Stokes' Law). Results tended to be erratic, however, when any appreciable quantity of material was transported as bed load.

Of greater concern are the differences in performance of the commercial automatic samplers. The data conclusively demonstrate that there can be marked differences in the results obtained with different types of sampling equipment, even under identical, controlled flow conditions.

It was not the purpose of this brief series of tests to evaluate the different design approaches used by commercial manufacturers of automatic sampling equipment. The results of the tests do point out the critical urgency for such work to be performed, however. As suggested by other work and demonstrated by the present effort, some water quality data now in existence may be considered suspect, at least insofar as suspended solids are concerned. Thus, there is an urgent need for determining the capabilities of various types of sample collection systems to gather representative samples of wastewater flows over a wide range of characteristics. This is especially critical for equipment to be used in storm and combined sewer flows which often contain large amounts of heavier suspended solids.

Another great area of concern is in the ability to sample floatables and bed load solids. The prototype sampler was not designed to sample either in a truly representative sense, and no claim should be inferred as to its ability to do so. Such materials (including undissolved or nonemulsified oil and grease) may, and in all likelihood will, be present in many storm and combined sewer flows, and sampling of them is necessary if one is to be able to account for all pollutant loadings in a time-mass-discharge sense. No equipment exists today that is well suited for these purposes, and a program to develop devices that can be used for such wastewater characterization appears to be sorely needed.

SECTION IX

REFERENCES

1. Shelley, P. E. and Kirkpatrick, G. A., "An Assessment of Automatic Sewer Flow Samplers," USEPA Research and Monitoring Environmental Protection Technology Series Report No. EPA-R2-73-261 (1963).

2. Inter-Agency Committee on Water Resources, "Laboratory Investigation of Suspended Sediment Samplers," Report No. 5 (1941).

3. Inter-Agency Water Resources Council, "Laboratory Investigation of Pumping Sampler Intakes," Report No. T (1966).

4. Inter-Agency Water Resources Council, "Investigation of a Pumping Sampler With Alternate Suspended Sediment Handling Systems," Report No. Q (1962).

5. Schulz, E. F., Wilde, R. H. and Albertson, M. L., "Influence of Shape on the Fall Velocity of Sedimentation Particles," Missouri River Division Sedimentation Series Report No. 5, U.S. Army Corps of Engineers, Omaha, Nebraska (1954).

6. Inter-Agency Committee on Water Resources, "Some Fundamentals of Particle Size Analysis" Report No. 12 (1957).

7. Mkhitaryan, A. M., Gidravlika i Osnovy Gazodinamiki, Gosudarstvennoe Izdatel'stvo Tekhnicheskoi Literatury UkrSSR, Kiev (1959).

8. Knorz, V. S., "Beznapornyi gidrotransport i ego raschet," Izvestiya Vsesoyuznogo Naucho-Issledovatel'skogo Instituta Gidravliki, Vol. 44 (1951).

9. Water Pollution Control Federation, Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9 (1970).

10. U.S. Environmental Protection Agency, "Methods for Chemical Analysis of Water and Wastes - 1971," Report No. 16020 --- 07/71.

11. Harris, D. J. and Keffer, W. J., "Wastewater Sampling Methodologies and Flow Measurement Techniques", USEPA Region VII Surveillance and Analysis Division, Report No. EPA 907/9-74-005 (1974).

12. Inter-Agency Committee on Water Resources, "Determination of Fluvial Sediment Discharge", Report No. 14 (1963).

SECTION X

APPENDIX

CONTROLLED LABORATORY TESTING DATA

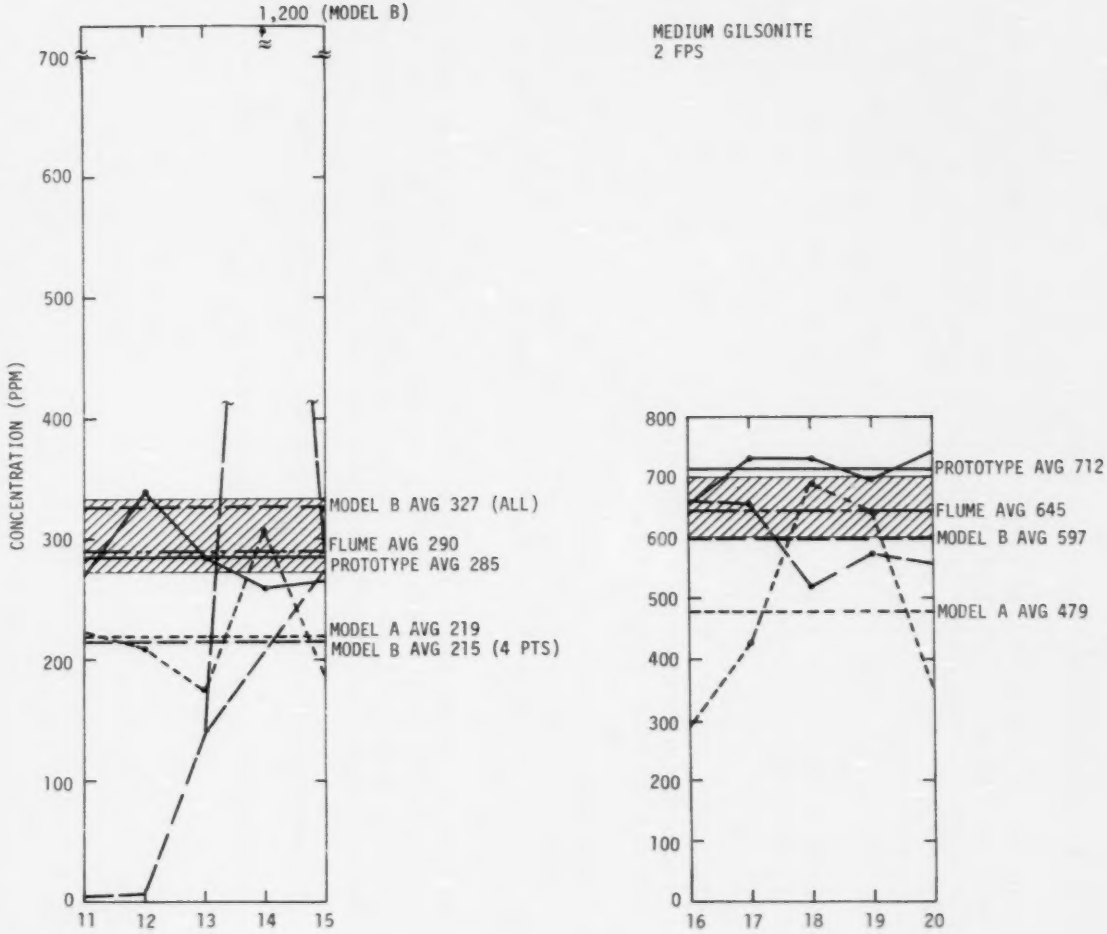
This Appendix contains plots of the raw data that were taken during the comparative testing phase of the project. They are plotted by run number, the first two digits of which are the day of the month (July, 1974) when that run was made, while the digit(s) across the bottom of the plot were assigned in chronological order for the day in question.

Five data replicates were taken for each set of test parameters involved. The concentrations for each piece of equipment, as determined by laboratory analysis, are plotted, and the simple arithmetic average of the five points is indicated as a straight line. The straight line representing the average flume concentration is, in most cases, the simple average of ten calibration samples, five taken just before and five taken right after each run. The shaded area indicates the band within which all of the flume calibration data fell. All concentrations are given in parts per million on a weight basis and may alternatively be considered as being given in milligrams per liter.

Also given on each page are the velocity of the flow and the suspended solid involved. Flow velocities are given in feet per second; multiply by 0.3 to convert to meters per second. The characteristics of the suspended solids are:

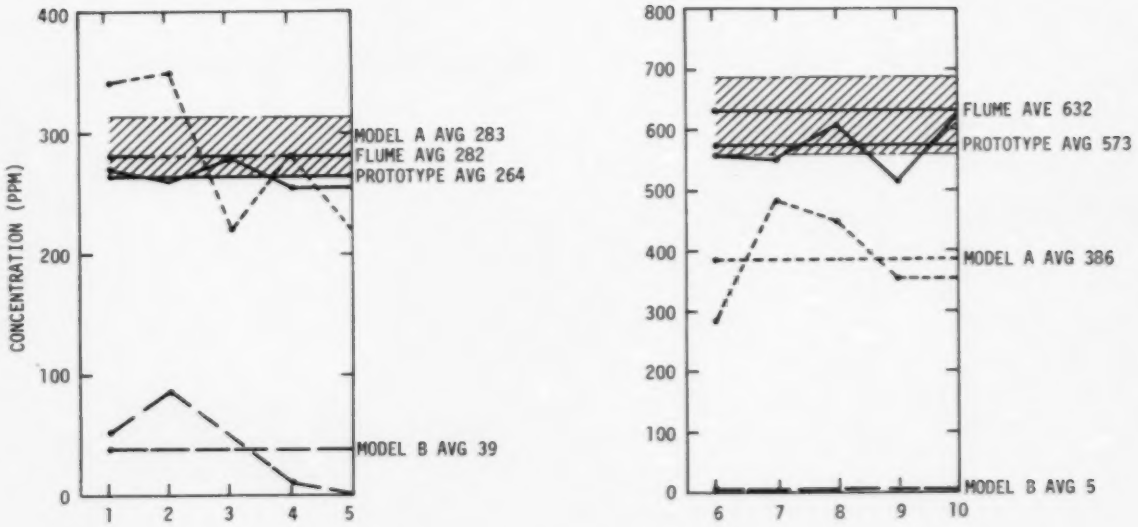
Medium gilsonite: $1.68 \leq d \leq 2.00$ mm, S.G. = 1.06

Fine sand: $0.105 \leq d \leq 0.125$ mm, S.G. = 2.65

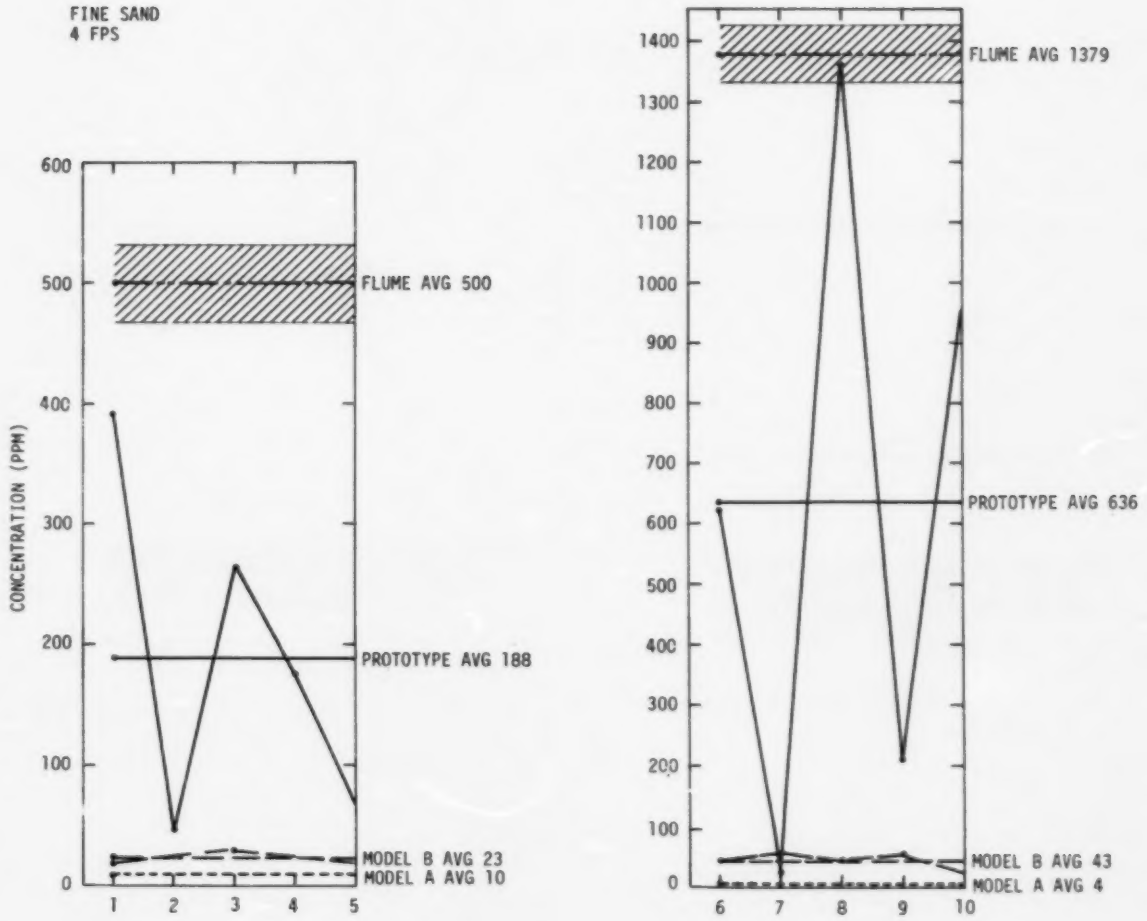

1,200 (MODEL B)
MEDIUM GILSONITE
2 FPS
CONCENTRATION (PPM)
700
600
500
400
300
200
100
0
11
12
13
14
15
16
17
18
19
20
800
MODEL B AVG 327 (ALL)
FLUME AVG 290
PROTOTYPE AVG 285
MODEL A AVG 219
MODEL B AVG 215 (4 PTS)
PROTOTYPE AVG 712
FLUME AVG 645
MODEL B AVG 597
MODEL A AVG 479

Run No. 26-

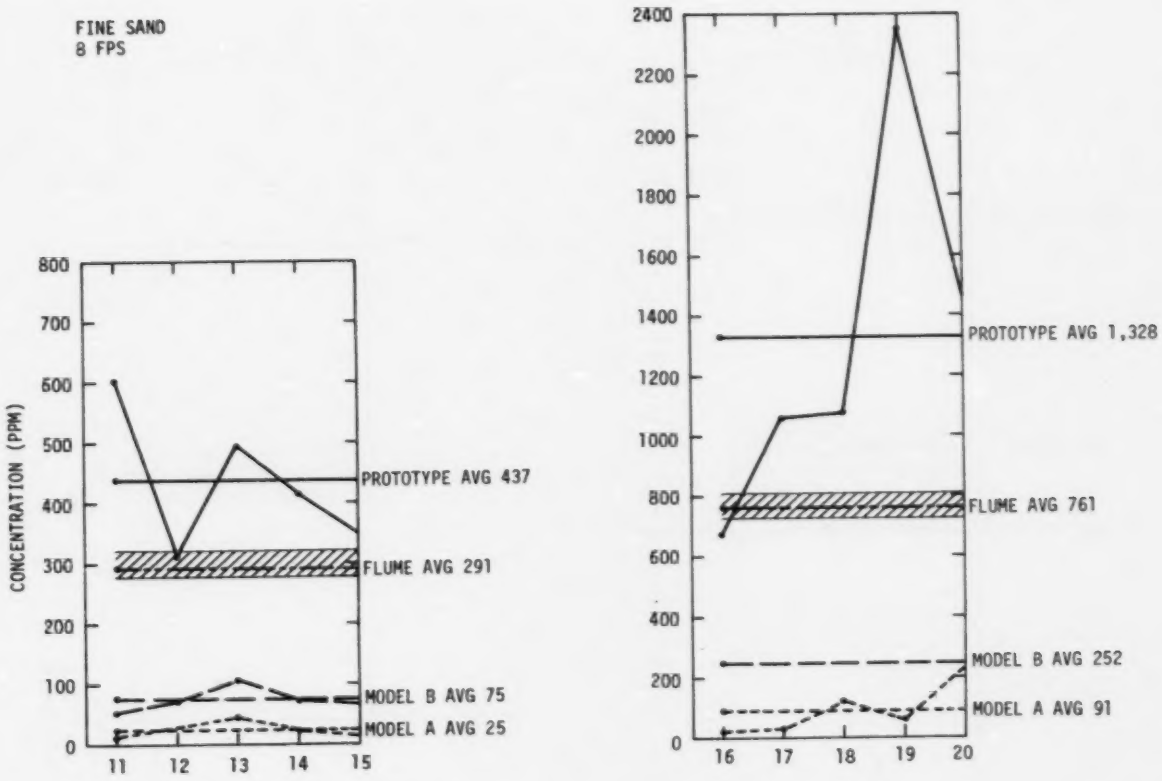
MEDIUM GILSONITE
4 FPS



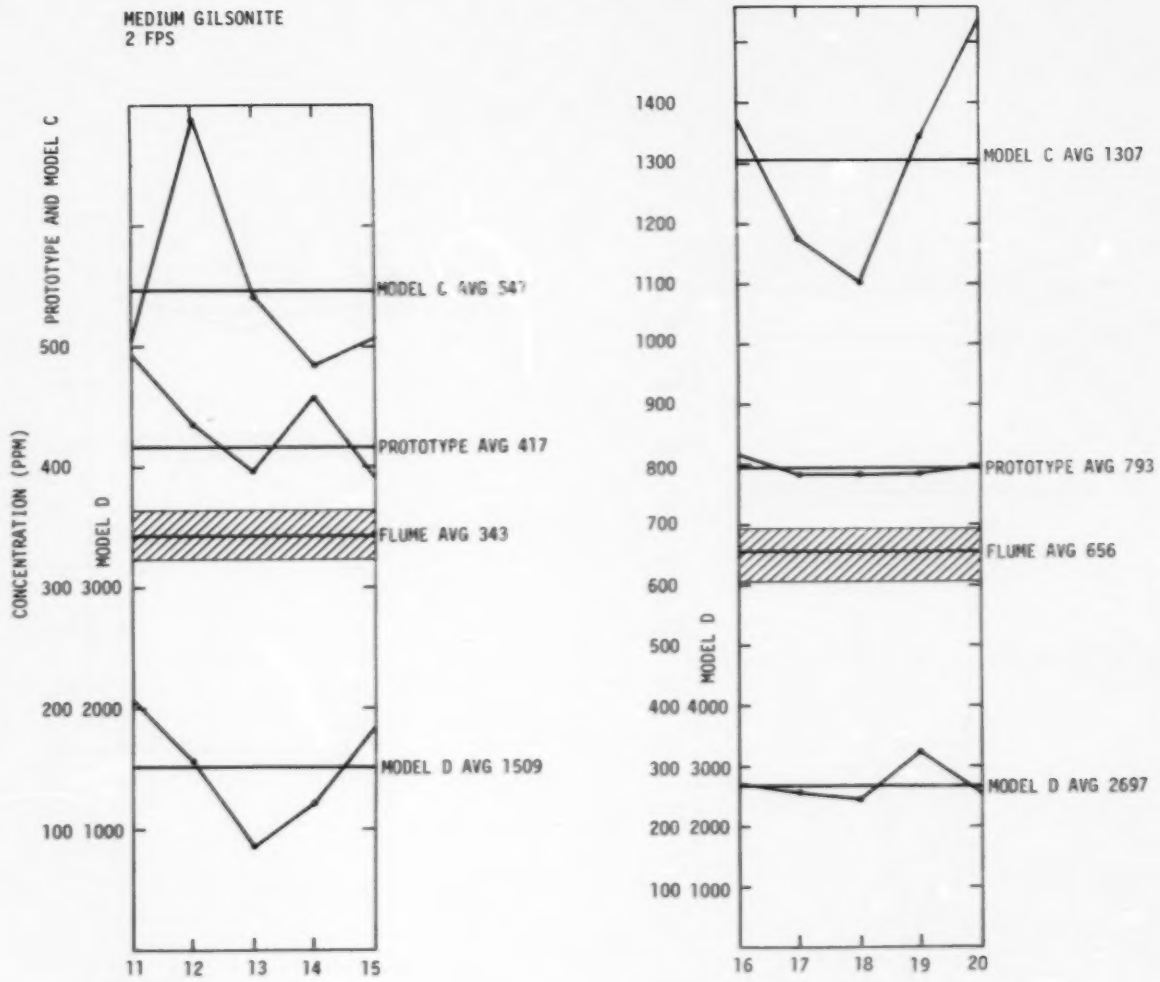
Run No. 26-


FINE SAND
4 FPS
CONCENTRATION (PPM)
600
500
400
300
200
100
0
1
2
3
4
5
FLUME AVG 500
PROTOTYPE AVG 188
MODEL B AVG 23
MODEL A AVG 10
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
6
7
8
9
10
FLUME AVG 1379
PROTOTYPE AVG 636
MODEL B AVG 43
MODEL A AVG 4

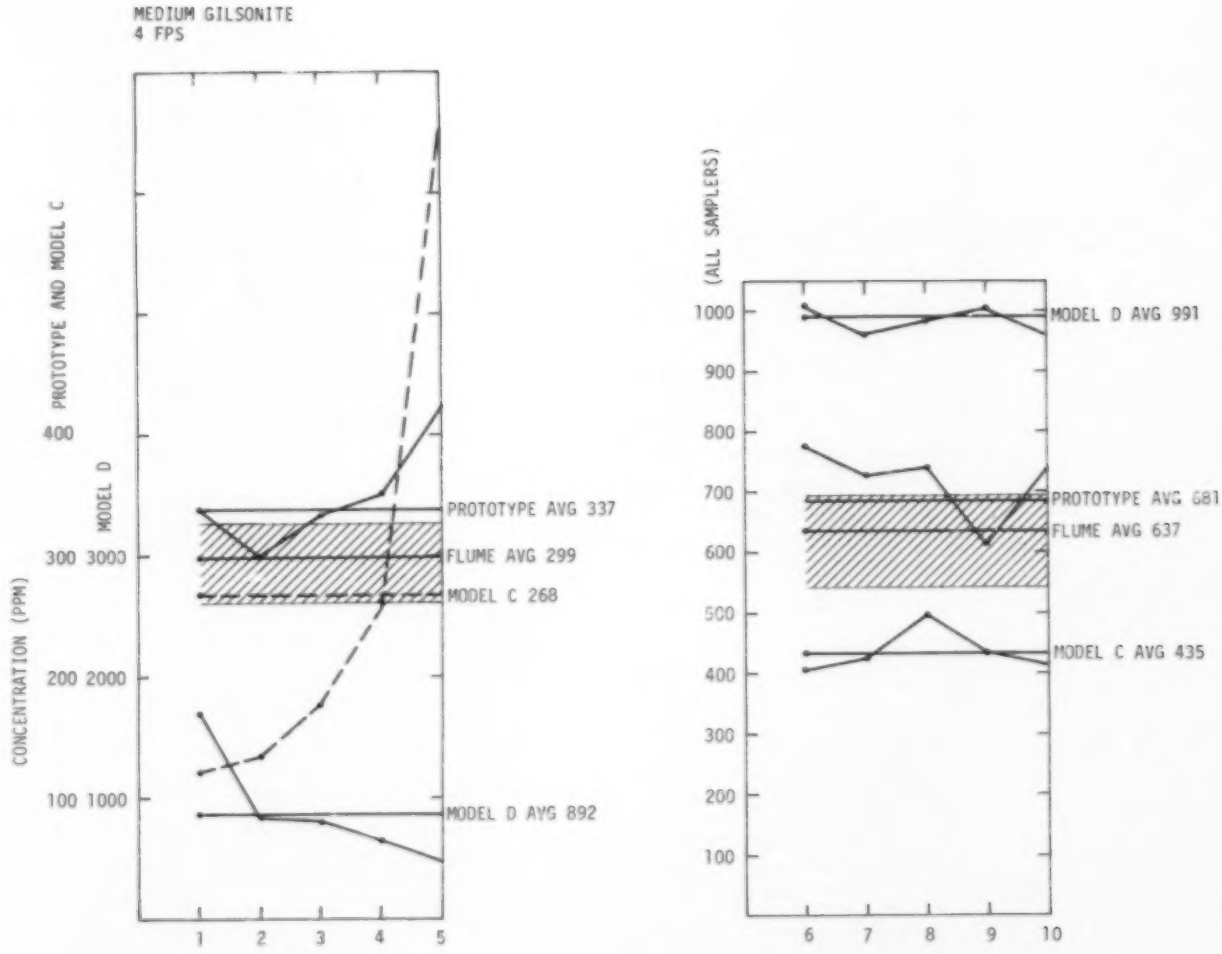
Run No. 25-


FINE SAND
8 FPS
CONCENTRATION (PPM)
800
700
600
500
400
300
200
100
0
11
12
13
14
15
PROTOTYPE AVG 437
FLUME AVG 291
MODEL B AVG 75
MODEL A AVG 25
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
16
17
18
19
20
PROTOTYPE AVG 1,328
FLUME AVG 761
MODEL B AVG 252
MODEL A AVG 91

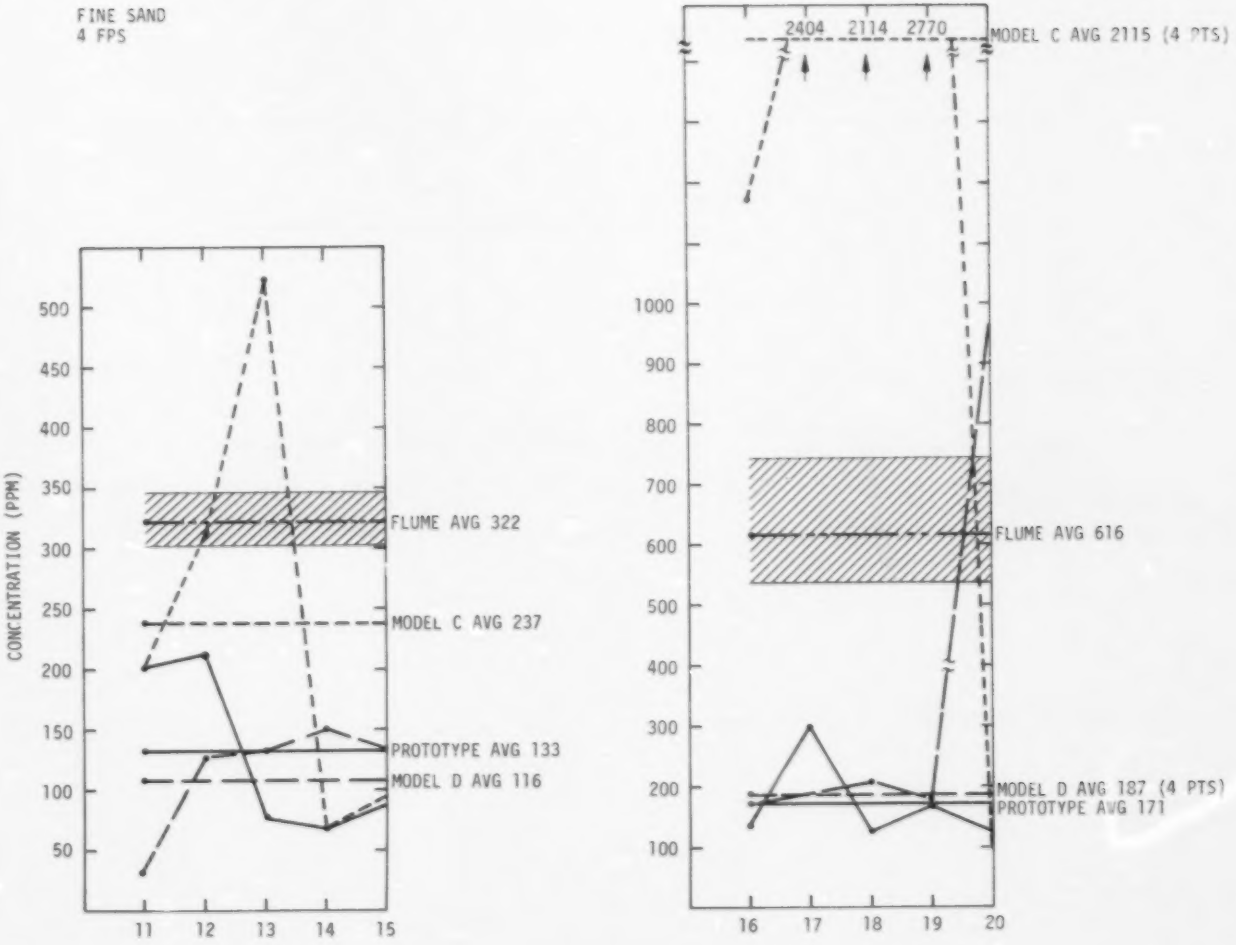
Run No. 25-


MEDIUM GILSONITE
2 FPS
CONCENTRATION (PPM)
PROTOTYPE AND MODEL C
MODEL D
500
400
300 3000
200 2000
100 1000
MODEL C AVG 547
PROTOTYPE AVG 417
FLUME AVG 343
MODEL D AVG 1509
11
12
13
14
15
1400
1300
1200
1100
1000
900
800
700
600
500
400 4000
300 3000
200 2000
100 1000
MODEL C AVG 1307
PROTOTYPE AVG 793
FLUME AVG 656
MODEL D AVG 2697
16
17
18
19
20

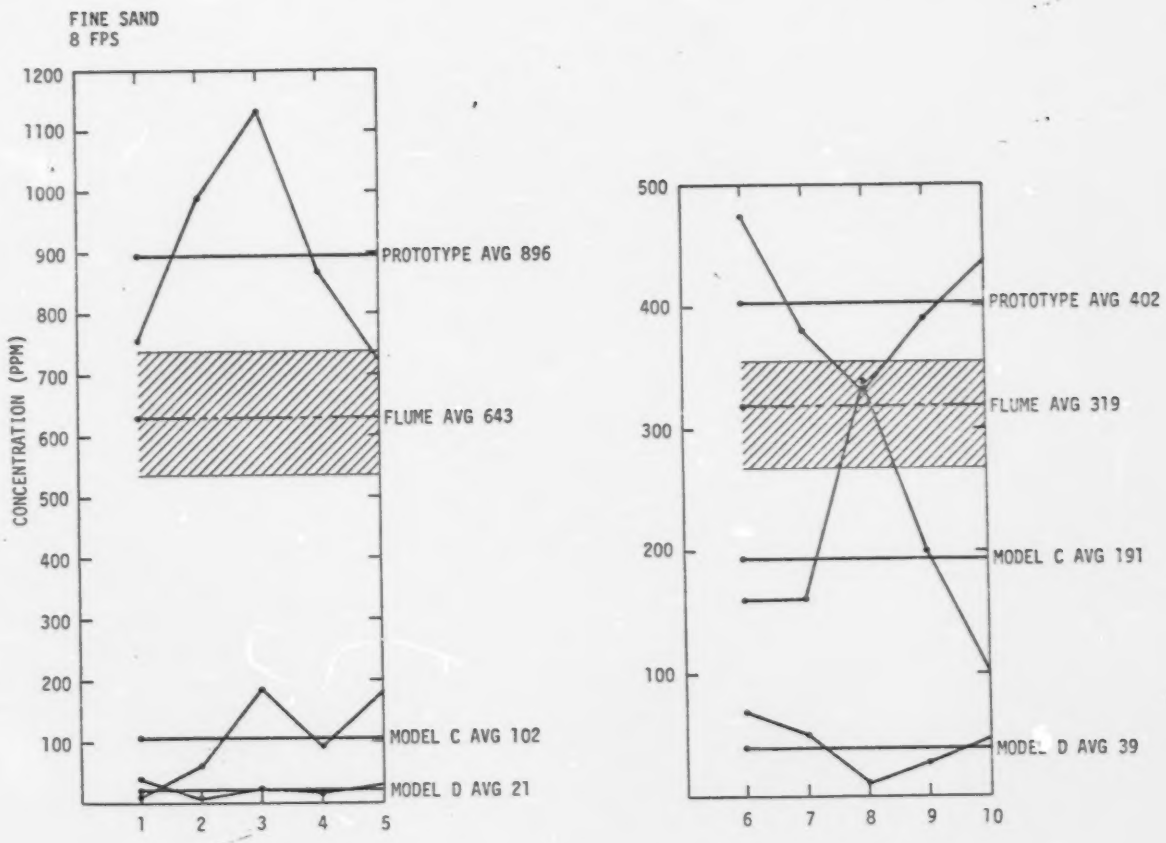
Run No. 30-


MEDIUM GILSONITE
4 FPS
CONCENTRATION (PPM)
PROTOTYPE AND MODEL C
MODEL D
400
300 3000
200 2000
100 1000
PROTOTYPE AVG 337
FLUME AVG 299
MODEL C 268
MODEL D AVG 892
1
2
3
4
5
(ALL SAMPLERS)
1000
900
800
700
600
500
400
300
200
100
MODEL D AVG 991
PROTOTYPE AVG 681
FLUME AVG 637
MODEL C AVG 435
6
7
8
9
10

Run No. 30-


FINE SAND
4 FPS
CONCENTRATION (PPM)
500
450
400
350
300
250
200
150
100
50
11
12
13
14
15
FLUME AVG 322
MODEL C AVG 237
PROTOTYPE AVG 133
MODEL D AVG 116
2404
2114
2770
MODEL C AVG 2115 (4 PTS)
1000
900
800
700
600
500
400
300
200
100
16
17
18
19
20
FLUME AVG 616
MODEL D AVG 187 (4 PTS)
PROTOTYPE AVG 171

Run No. 29-


FINE SAND
8 FPS
CONCENTRATION (PPM)
1200
1100
1000
900
800
700
600
500
400
300
200
100
1
2
3
4
5
PROTOTYPE AVG 896
FLUME AVG 643
MODEL C AVG 102
MODEL D AVG 21
500
400
300
200
100
6
7
8
9
10
PROTOTYPE AVG 402
FLUME AVG 319
MODEL C AVG 191
MODEL D AVG 39

Run No. 29-